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MDC-TR-66-37

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AIR FORCE MISSILE DEVELOPMENT CENTER
TECHNICAL REPORT

RAT SCAT CROSS SECTION MEASUREMENTS OF
017-2, ROCKET EXHAUST PLUMES

HAROLD C. MARLOW
MAJOR, USAF MDRT

December 1966

RAT SCAT
RADAR TARGET SCATTER DIVISION
HOLLOMAN AIR FORCE BASE, NEW MEXICO

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In addition to security requirements which apply to this document and must be met, each transmittal outside the Department of Defense must have prior approval of Air Force Missile Development Center, MDRT.

FRXM- 017-2
RSFW 66/1/C/14
COPY NR. [redacted]

MDC-TR-66-37

RAT SCAT CROSS SECTION MEASUREMENTS OF 017-2, ROCKET EXHAUST PLUMES (U)

December 1966

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HAROLD C. MARLOW, Major, USAF
Chief, Radar Target Scatter Division

RAT SCAT
Radar Target Scatter Division
Missile Development Center
Air Force Systems Command
Holloman Air Force Base, New Mexico

RSFW66/1/C/14

FOREWORD

This Air Force Report is based upon the actual radar cross section measurements made at the Radar Target Scatter Division (RAT SCAT), of AFMDC. RAT SCAT is located on the Alkali Flats. Holloman AFB, New Mexico. This Facility is operated and maintained by the General Dynamics Corporation, Fort Worth Division, and under the specific direction of the Air Force Missile Development Center. The Project or Program Monitor is Major Harold C. Marlow. Correspondence pertaining to this report should be addressed to the attention of MDRT.

This technical report has been reviewed and is approved.

Walter L. Carss

WALTER L. CARSS, Colonel, USAF
Director of Technical Support

UNCLASSIFIED ABSTRACT

Static radar cross section data of plumes from small liquid and solid propellant rocket motors were obtained at RAT SCAT, Air Force Missile Development Center, Holloman Air Force Base, New Mexico. A total of 42 monostatic measurements were made at UHF and upper L-band frequencies. These measurements are believed to be the first true radar cross section measurements of actual rocket plumes.

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SECTION I

INTRODUCTION

This report documents radar cross section measurements of exhaust plumes from small liquid and solid propellant rocket motors under RAT SCAT Control Number 017-2. A total of 42 measurements were made at 450 and 2000 megahertz. Measurements were made using different aluminum contamination seeding rates carefully controlled as shown in Table II, Page 8 and 9, three incidence angles, and two exit pressures to determine the reflectivity effects. Specific test conditions are presented in Section II along with the reproduced rectilinear data plots.

A general description of the RAT SCAT site and operational procedures are included in Appendices A and B.

The measurements made and data contained herein are certified as to quality, repeatability, and accuracy by Air Force representatives on site (AFMDC, MDRT).

The data contained herein was requested by REFSRAM 017-2 as submitted by the Rocket Test Facility at Edwards AFB, RPMCP (RTD).

SECTION II

TEST CONDITIONS AND RESULTS

Test Conditions

Radar cross section measurements were made in support of an Aerochem Research Laboratory contract with RTD. Rocket motor firings were conducted by Thiokol Chemical Company, Reaction Motors Division.

The rocket exhaust plumes measured were generated by small rocket motors of the approximately 2000 pound thrust. Thiokol TU-168 motors were used for the solid propellant plumes. These motors are of the AP composite type. Two each center perforated, end burning sections were used to obtain a constant burn rate during the three second burn time. The liquid propellant tests were performed with a mixed hydrazine fuel (MHF-5) and nitrogen tetroxide oxidizer (N_2O_4).

The rocket motors with their associated test stand had to be shielded in order to isolate the plume radar reflection from the motor test stand and associated equipment. Ground plane effect made it difficult to use the RAT SCAT pits for this purpose as it was desired to have strong illumination over the entire rocket exhaust plume. A shaped gypsum baffle was used to shield the rocket motors, placing the nozzle at a height of 10 feet above ground level. The plume was directed upwards and was about 4 feet long for the liquid propellant motors and about 9 feet for the solid propellant motors. The shaped gypsum mound, shown in Figures 1 and 2, had a rounded cross section with a peak height of 10 feet, a width of 30 feet and a length of 80 feet. A wire cage capped the rear of the baffle to minimize reflection from the discontinuities and equipment at the rear of the mound. The wire was faired into the earthwork to provide a smooth electrical transition. The scheme gave background returns of around -35 to -40 dbsm both at 2000 MH_z and at 450 MH_z. While the background was generally acceptable the ground plane reflections from the baffle itself perturbed the field in the target (plume) area. We did try the use of a peaked (triangular cross section) baffle and it did not significantly improve the energy distribution. Radar absorption material (RAM) fences on the earthwork baffle improved vertical field distribution somewhat at the expense of background. In the tradeoff between background level and target illumination the low background was judged the more important at 2000 MH_z; consequently, a probe of the 2-way field pattern shows an amplitude variation across the target zone. Calibration was performed with a precision sphere located in the plume target zone.

At 450 MH_z, for the liquid propellant rocket plume measurements, absorber fences were used on the earthwork baffle to improve the illumination pattern without a serious increase in background return. The vertical field pattern with this configuration was acceptable for the 4 foot target zone.

For the solid propellant rocket plume measurements at 450 MH_z the rocket motors were placed behind a stack of radar absorption material with the nozzle at a height of 5 feet in order to obtain an acceptable vertical field pattern over the 9 foot target zone.

Boxcar detector output (wide pulses representing the amplitude of the gated video pulses) was monitored to obtain the amplitude of each reflected pulse. This increased the information bandwidth to approximately 500 cycles per second as compared to approximately 3 cycles per second for the normal system recording. This signal was recorded on a user provided special ampex tape recorder.

The radar measurement parameters are given in Table I.

Table I MEASUREMENT PARAMETERS

Firing No.	Range	Ant. Height	Cal. Height	Nozzle Height	Pulse Width	Peak Power
5-9	1500 ft.	9 ft.	11.5 ft.	10 ft.	.2μsec	1kw
10-14	1500	9	11.5	10	.2	1kw
15-21	1500	9	11.5	10	.2	1kw
22-25	1500	9	11.5	10	.2	1kw
26-30	1500	9	11.5	10	.2	1kw
31-41	600	24	14	11	.1	1kw
42-47	500	24	11	5	.2	1kw
48	500	24	11	5	.2	1kw

The pulse repetition frequency was 1000 pulses per second and the range gate width was 0.1 microsecond for all firings. Firings through #41 were done using the earthwork baffle. Firing numbers 5 through 30 were at 2000 MH_z and numbers 31 through 48 at 450 MH_z.

Figure 1 EARTHWORK BAFFLE WITH TYPICAL LIQUID
PROPELLANT ROCKET PLUME

Figure 2 TYPICAL SOLID PROPELLANT ROCKET PLUME

Data Section

Pertinent rocket motor parameters and radar data are given in Table II, the Data Plot Index.

The abcissa does not represent azimuth, but time. The rectilinear recorder was run at a constant speed during each firing. The nominal speeds in degrees per second are given in the Data Plot Index. Ignition is on the right hand side of the plots, and burnout is on the left.

Background levels may be read directly from each data plot as the level before and after the firing. The background was often different from run to run due to movement of the rocket motor from one pitch angle to another. Motion occuring during the firing, however, was negligible. Fine adjustments in radar absorption material position and in the position of a fixed scatterer at the same range as the target were also made between runs to lower background return. Although the rocket plume is basically of a cylinderical shape, the backscattered energy from this non-conductive target can not be considered to be coherent. Therefore, the interference between the background and target is quite low for all measurements (reference Figure A-2).

The run numbers in this report are not necessarily sequential. Setup runs (calibration, post calibration, preliminary background runs, etc.) are necessary but are not included.

CONTROL NUMBER 017-2 TABLE II DATA PLOT INDEX SHEET 1

PAGE NO.	RUN	FREQ (MHz)	POLARI-ZATION	PITCH ANGLE	ROLL ANGLE	TARGET CONFIGURAT Firing No.	Seed (Al)	Exit Press
10	88	2000	H	90 (Plume	Vertical)	5 Liquid	1000 ppm	3.4
11	90	2000	V	90		6 Liquid	1000 ppm	3.4
12	92	2000	V	90		8 Liquid	1000 ppm	3.4
13	93	2000	HV	90		9 Liquid	1000 ppm	3.4
14	103	2000	H	90		10 Liquid	1000 ppm	0.86
15	104	2000	H	60 (Pitched	away	11 Liquid	1000 ppm	0.86
16	105	2000	H	60 from	radar)	12 Liquid	1000 ppm	3.4
17	106	2000	H	60		13 Liquid	100 ppm	3.4
18	107	2000	H	60		14 Liquid	100 ppm	0.86
19	111	2000	H	90		15 Liquid	100 ppm	0.86
20	112	2000	H	90		16 Liquid	100 ppm	0.86
21	114	2000	H	90		17 Liquid	100 ppm	3.4
22	115	2000	H	120 (Pitched	to-	18 Liquid	100 ppm	3.4
23	116	2000	H	120 ward	radar)	19 Liquid	100 ppm	0.86
24	117	2000	H	90		20 Liquid	0 ppm	3.4
25	118	2000	H	90		21 Liquid	0 ppm	0.86
26	123	2000	H	90		23 Solid	16 percent	0.86
27	124	2000	H	90		24 Solid	16 percent	0.86
28	125	2000	H	90		25 Solid	16 percent	3.4
29	128	2000	H	90		26 Solid	5 percent	0.86
30	131	2000	H	120		27 Solid	5 percent	0.86
31	132	2000	H	60		28 Solid	5 percent	0.86
32	133	2000	H	60		29 Solid	16 percent	0.86
33	134	2000	H	120		30 Solid	16 percent	0.86
34	139	450	H	90		31 Liquid	0 ppm	0.86
35	140	450	H	90		32 Liquid	0 ppm	3.4
36	141	450	H	90		33 Liquid	1000 ppm	3.4
37	142	450	H	90		34 Liquid	1000 ppm	0.86
38	143	450	H	60		35 Liquid	1000 ppm	3.4
39	144	450	H	60		36 Liquid	1000 ppm	

TABLE II DATA PLOT INDEX SHEET 1

ARI-ION	PITCH ANGLE	ROLL ANGLE	TARGET CONFIGURATION AND REMARKS Firing No.	Seed (Al)	Exit Press Atm.	Nominal Recorder Speed	Notes
	90 (Plume	Vertical)	5 Liquid	1000 ppm	3.4	180 deg/sec	
	90		6 Liquid	1000 ppm	3.4	180 deg/sec	
	90		8 Liquid	1000 ppm	3.4	180 deg/sec	
	90		9 Liquid	1000 ppm	3.4	180 deg/sec	
	90		10 Liquid	1000 ppm	0.86	84 deg/sec	
	60 (Pitched	away	11 Liquid	1000 ppm	0.86	180 deg/sec	
	60 from	radar)	12 Liquid	1000 ppm	3.4	180 deg/sec	
	60		13 Liquid	100 ppm	3.4	180 deg/sec	
	60		14 Liquid	100 ppm	0.86	180 deg/sec	
	90		15 Liquid	100 ppm	0.86	180 deg/sec	
	90		16 Liquid	100 ppm	0.86	180 deg/sec	
	90		17 Liquid	100 ppm	3.4	180 deg/sec	
	120 (Pitched	to-	18 Liquid	100 ppm	3.4	180 deg/sec	
	120 ward	radar)	19 Liquid	100 ppm	0.86	180 deg/sec	
	90		20 Liquid	0 ppm	3.4	180 deg/sec	
	90		21 Liquid	0 ppm	0.86	180 deg/sec	
	90		23 Solid	16 percent	0.86	25 deg/sec	
	90		24 Solid	16 percent	0.86	25 deg/sec	(repeat of 23)
	90		25 Solid	16 percent	3.4	25 deg/sec	
	90		26 Solid	5 percent	0.86	25 deg/sec	
	120		27 Solid	5 percent	0.86	25 deg/sec	
	60		28 Solid	5 percent	0.86	25 deg/sec	
	60		29 Solid	16 percent	0.86	25 deg/sec	
	120		30 Solid	16 percent	0.86	25 deg/sec	
	90		31 Liquid	0 ppm	0.86	180 deg/sec	
	90		32 Liquid	0 ppm	3.4	180 deg/sec	
	90		33 Liquid	1000 ppm	3.4	180 deg/sec	
	90		34 Liquid	1000 ppm	0.86	180 deg/sec	
	60		35 Liquid	1000 ppm	3.4	180 deg/sec	
	60		36 Liquid	1000 ppm	0.86	180 deg/sec	

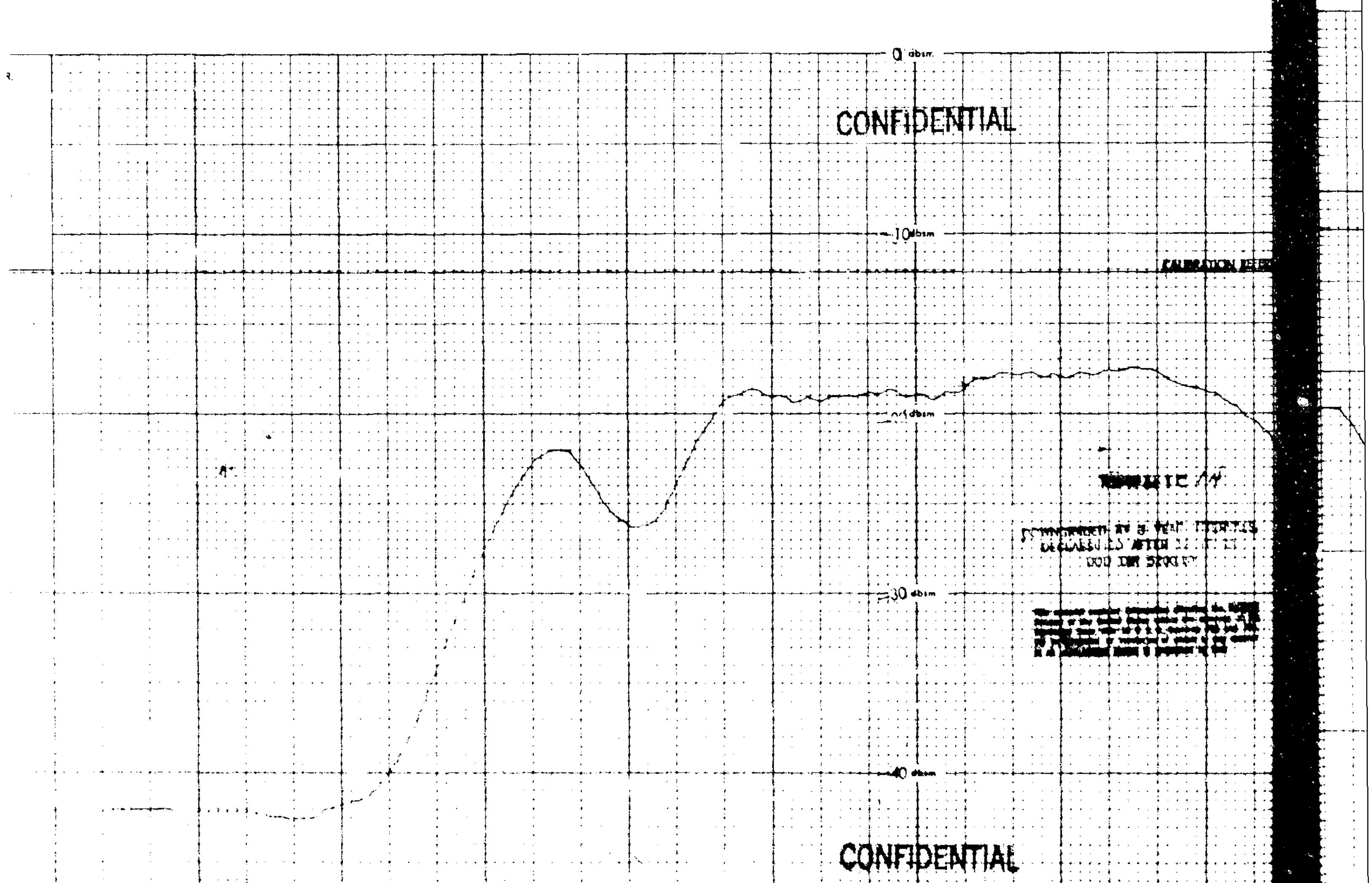
2

CONTROL NUMBER 017-2 TABLE II DATA PLOT INDEX SHEET 2

PAGE NO.	RUN	FREQ (MHz)	POLARIZATION	PITCH ANGLE	ROLL ANGLE	TARGET CONFIGURA		
						Firing No.	Seed (Al)	Exit Pre
40	145	450	H	120		37 Liquid	1000 ppm	0.86
41	146	450	H	60		38 Liquid	100 ppm	0.86
42	147	450	H	60		39 Liquid	100 ppm	3.4
43	148	450	H	90		40 Liquid	100 ppm	0.86
44	149	450	H	90		41 Liquid	100 ppm	3.4
45	177	450	H	90		42 Solid	16 percent	0.86
46	178	450	H	60		43 Solid	16 percent	0.86
47	182	450	H	90		44 Solid	16 percent	0.86
48	183	450	H	120		45 Solid	16 percent	0.86
49	184	450	H	90		46 Solid	16 percent	3.4
50	185	450	H	90		47 Solid	5 percent	0.86
51	189	450	H	120		48 Solid	5 percent	0.86

TABLE II DATA PLOT INDEX SHEET 2

PITCH ANGLE	ROLL ANGLE	TARGET CONFIGURATION AND REMARKS				
		Firing No.	Seed (Al)	Exit Press Atm.	Nominal Recorder Speed	Notes
120		37 Liquid	1000 ppm	0.86	180 deg/sec	
60		38 Liquid	100 ppm	0.86	180 deg/sec	
60		39 Liquid	100 ppm	3.4	180 deg/sec	
90		40 Liquid	100 ppm	0.86	180 deg/sec	
90		41 Liquid	100 ppm	3.4	180 deg/sec	
90		42 Solid	16 percent	0.86	120 deg/sec	
60		43 Solid	16 percent	0.86	120 deg/sec	
90		44 Solid	16 percent	0.86	120 deg/sec	(repeat of 42)
120		45 Solid	16 percent	0.86	120 deg/sec	
90		46 Solid	16 percent	3.4	120 deg/sec	
90		47 Solid	5 percent	0.86	120 deg/sec	
120		48 Solid	5 percent	0.86	120 deg/sec	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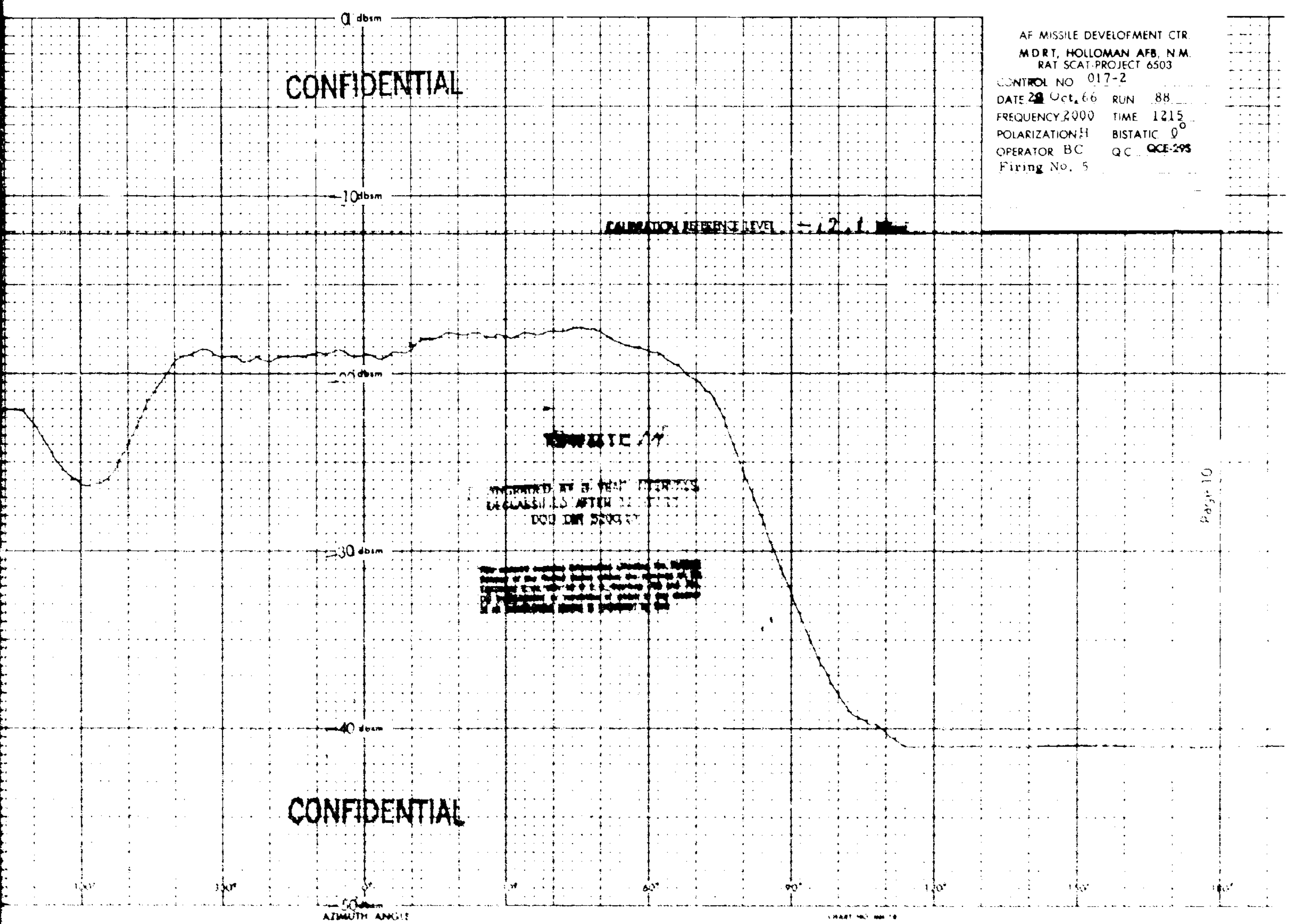
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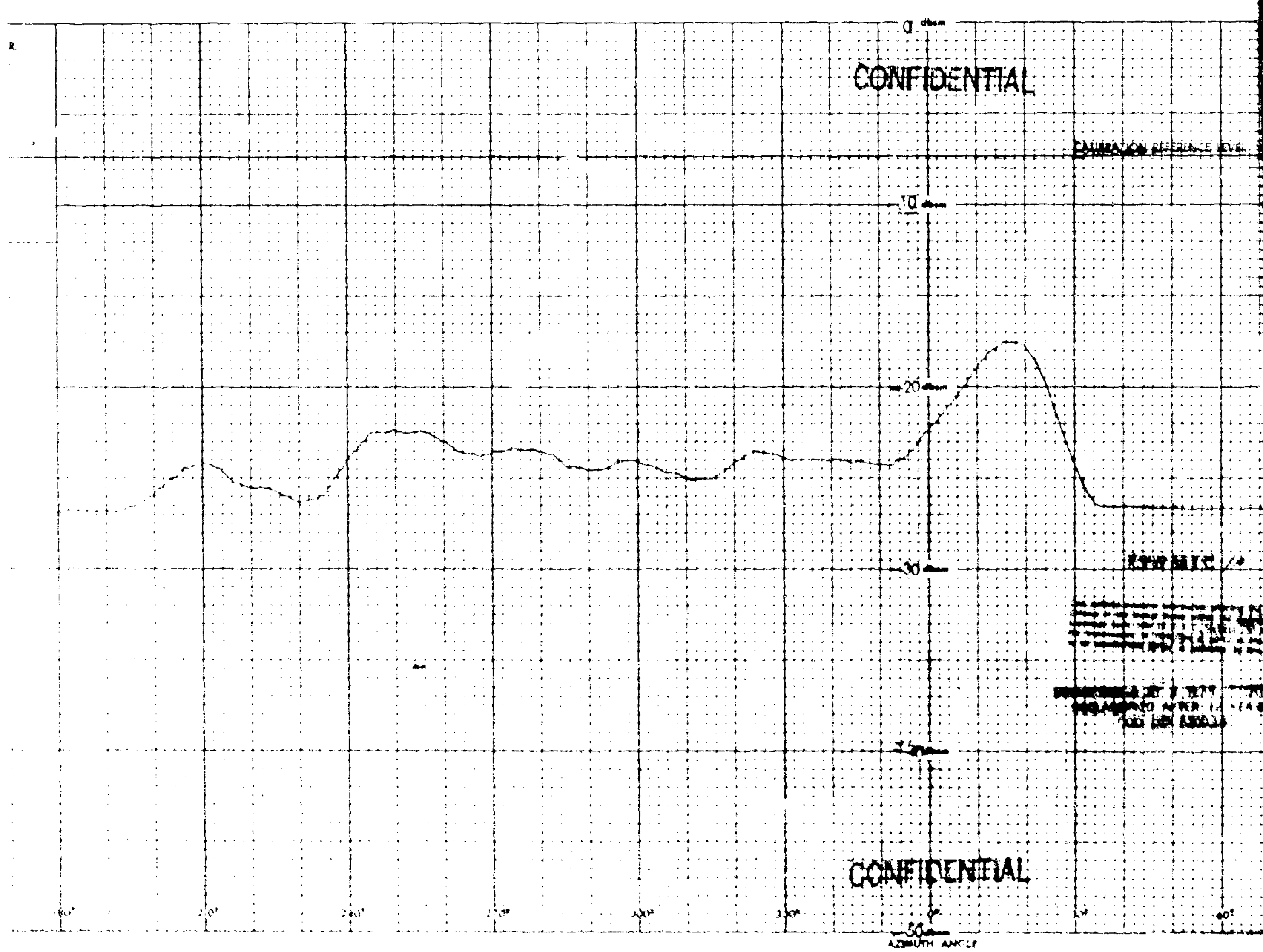

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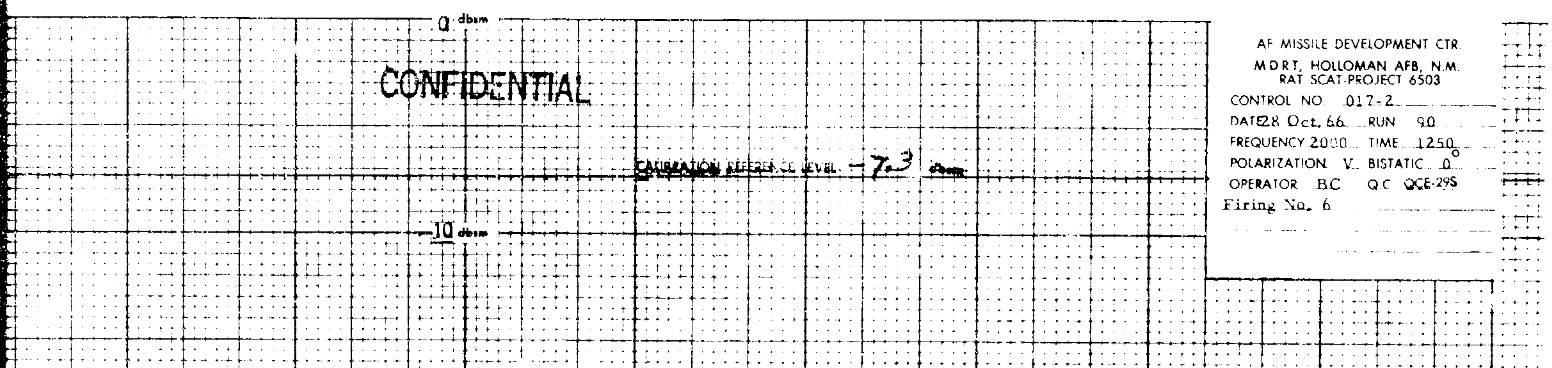
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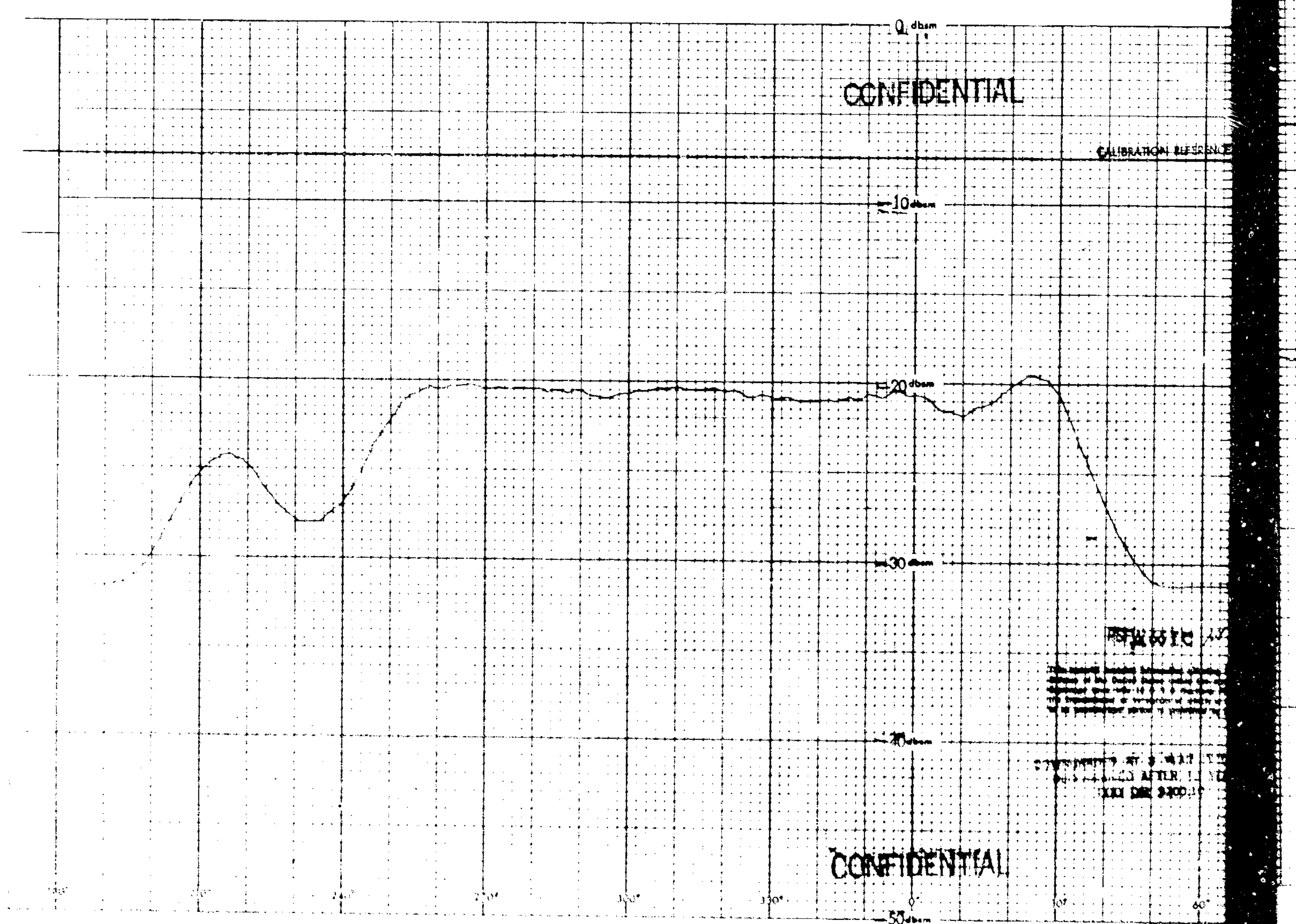
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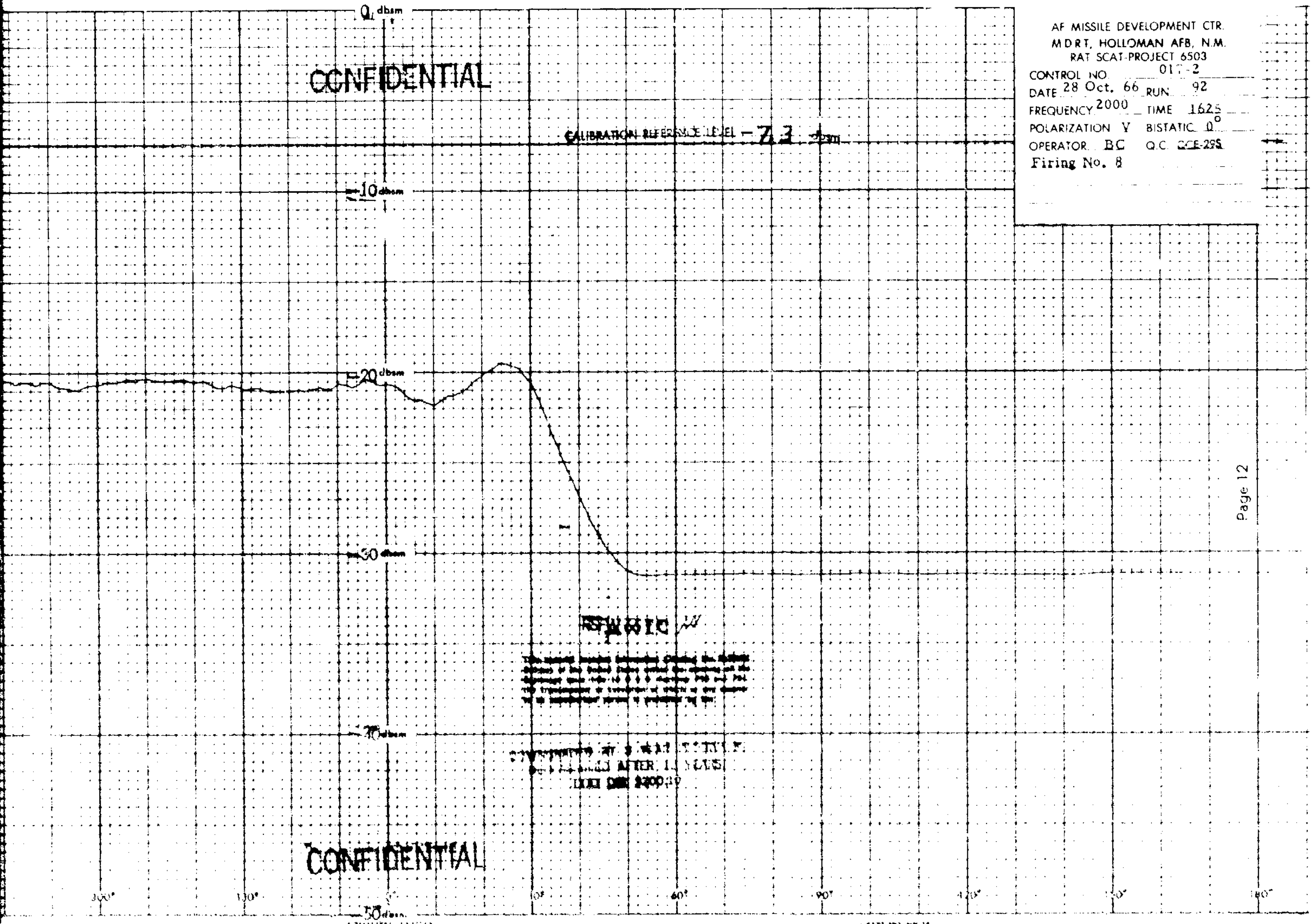
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CONFIDENTIAL
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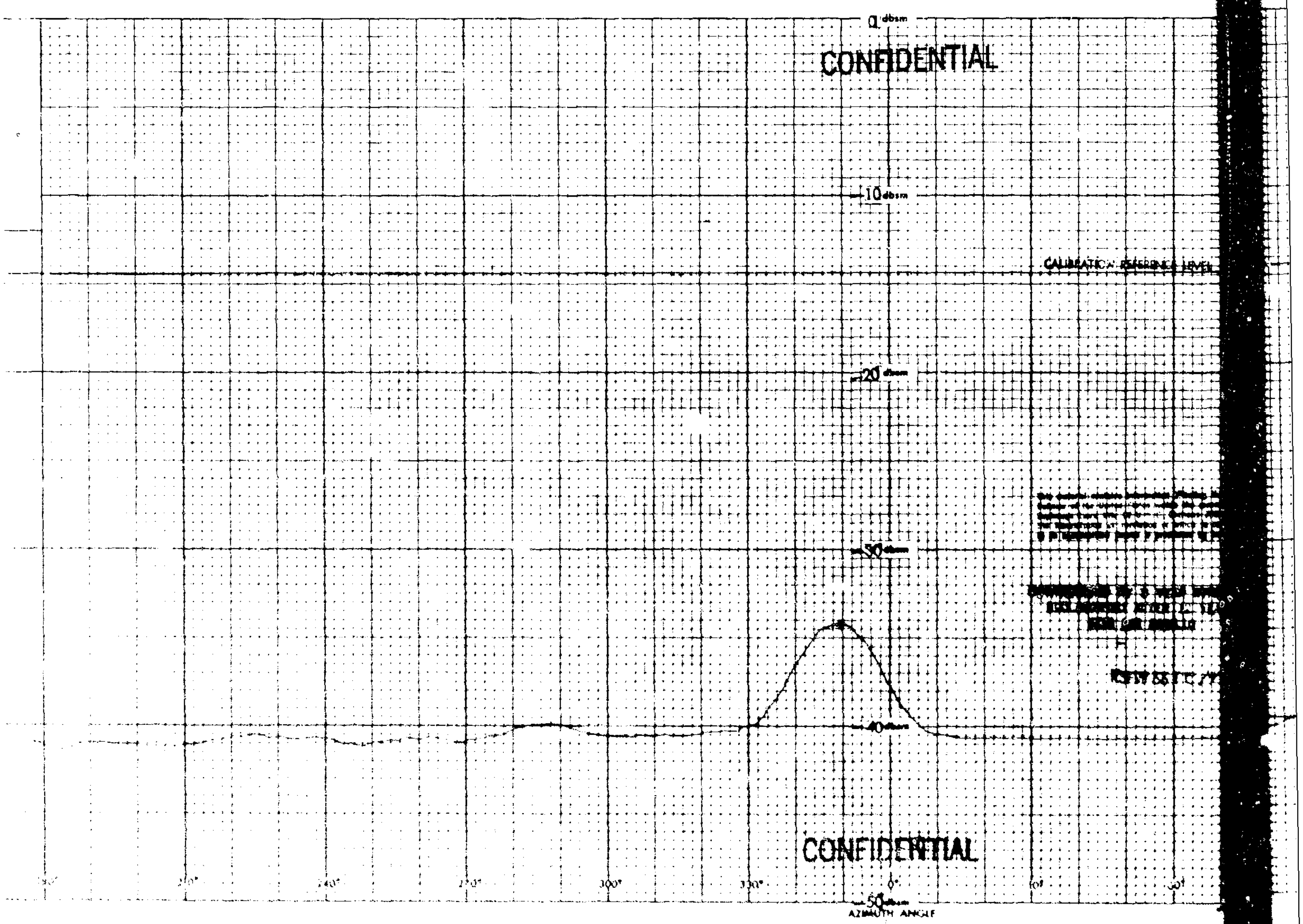
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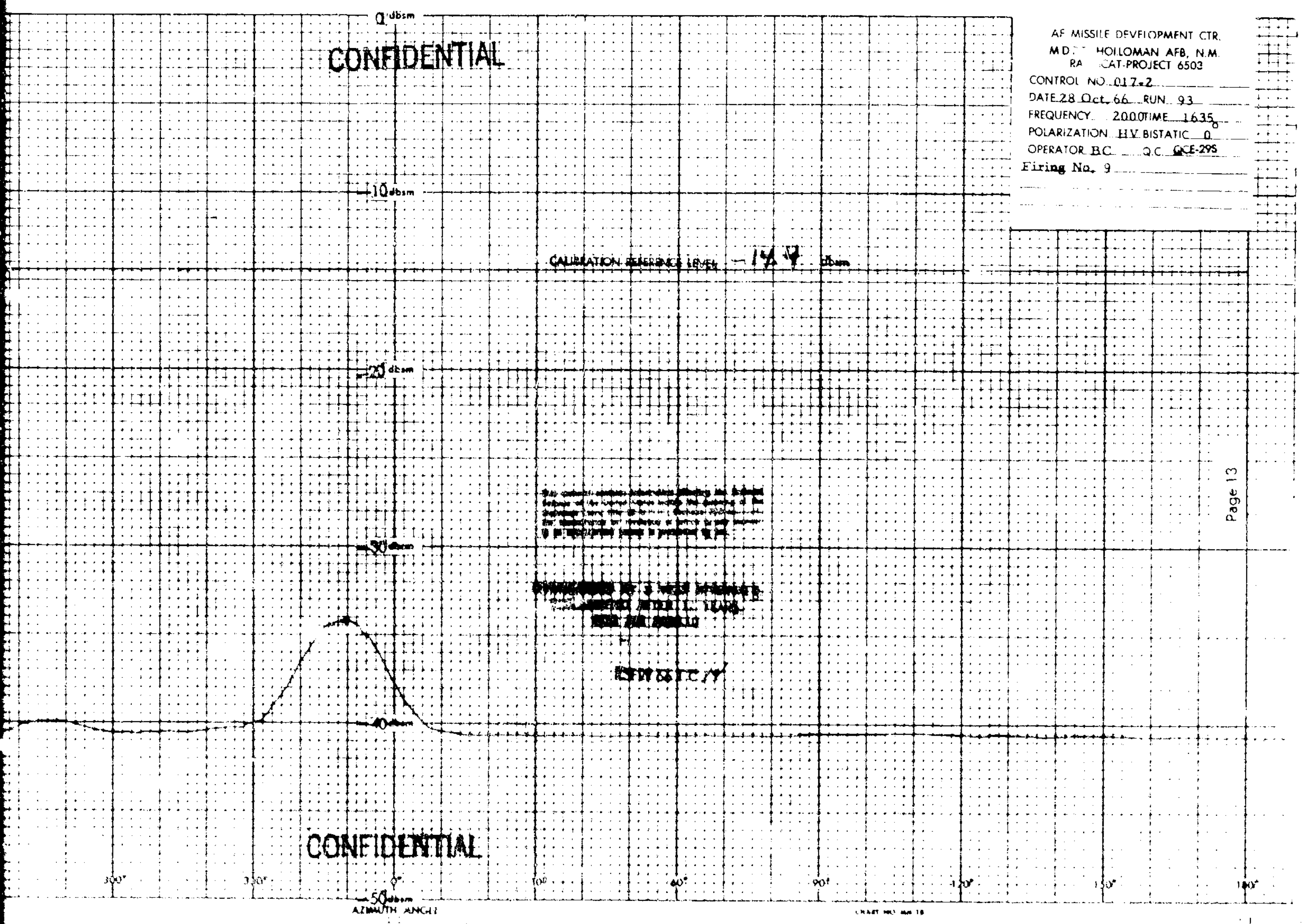
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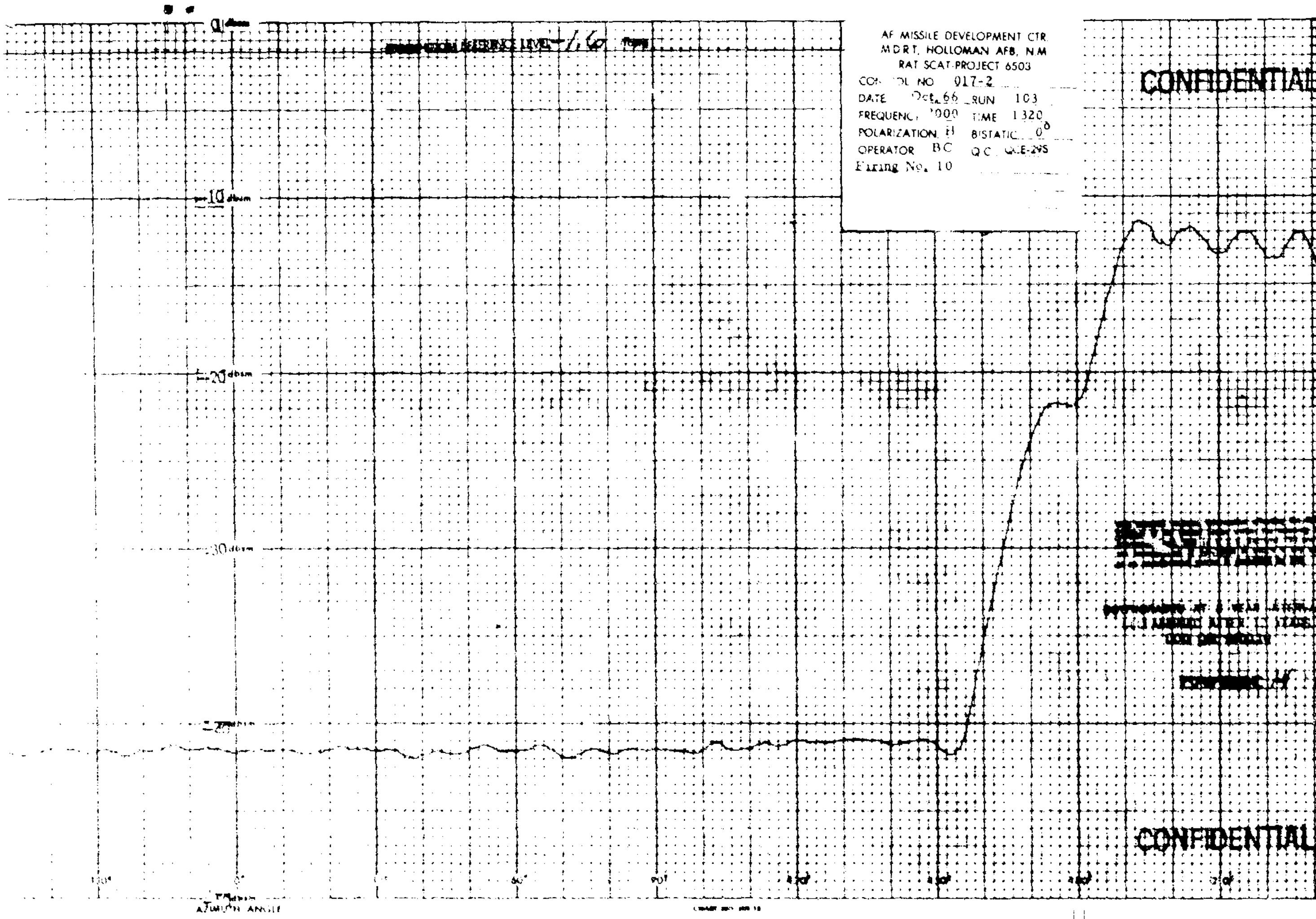
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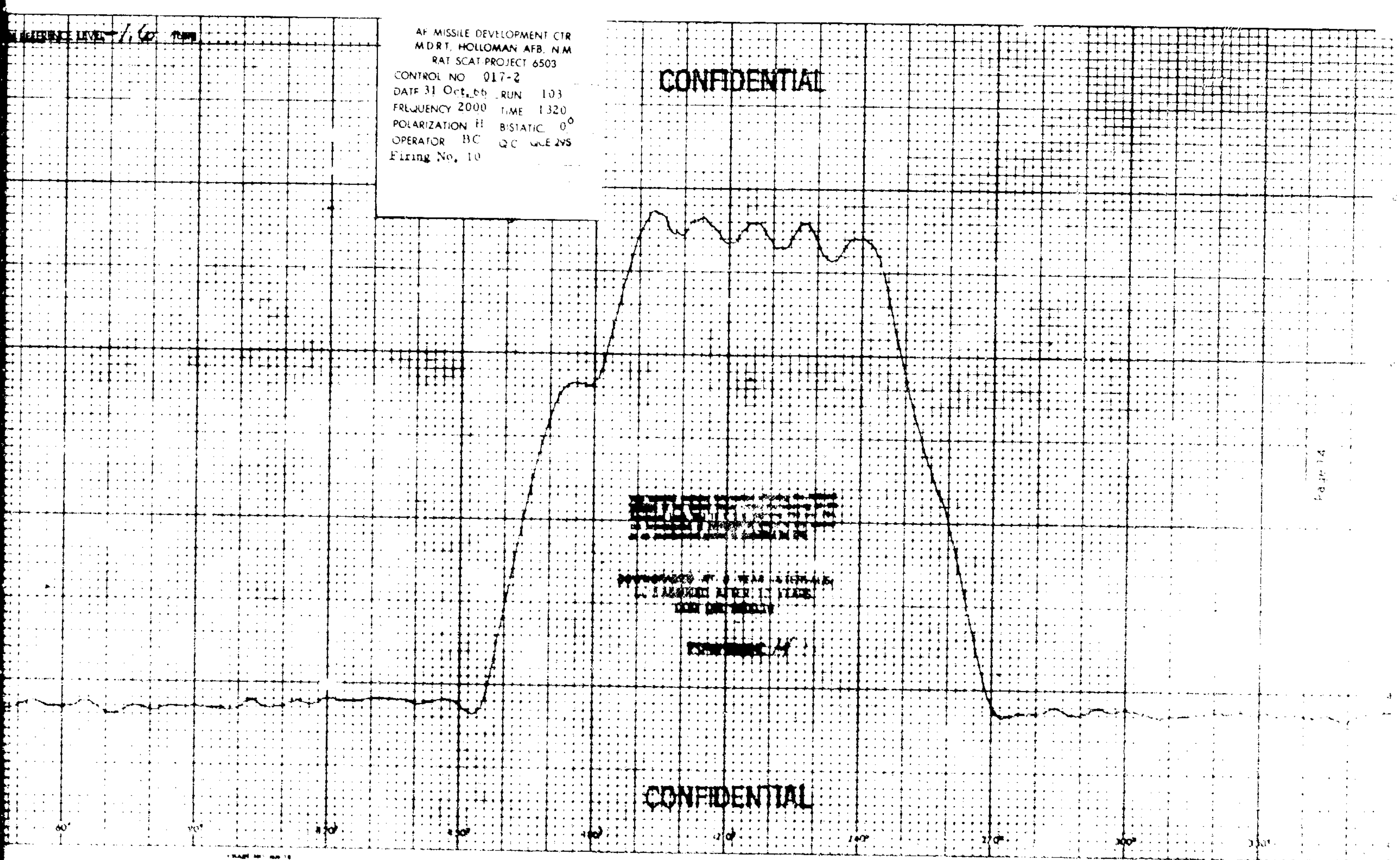
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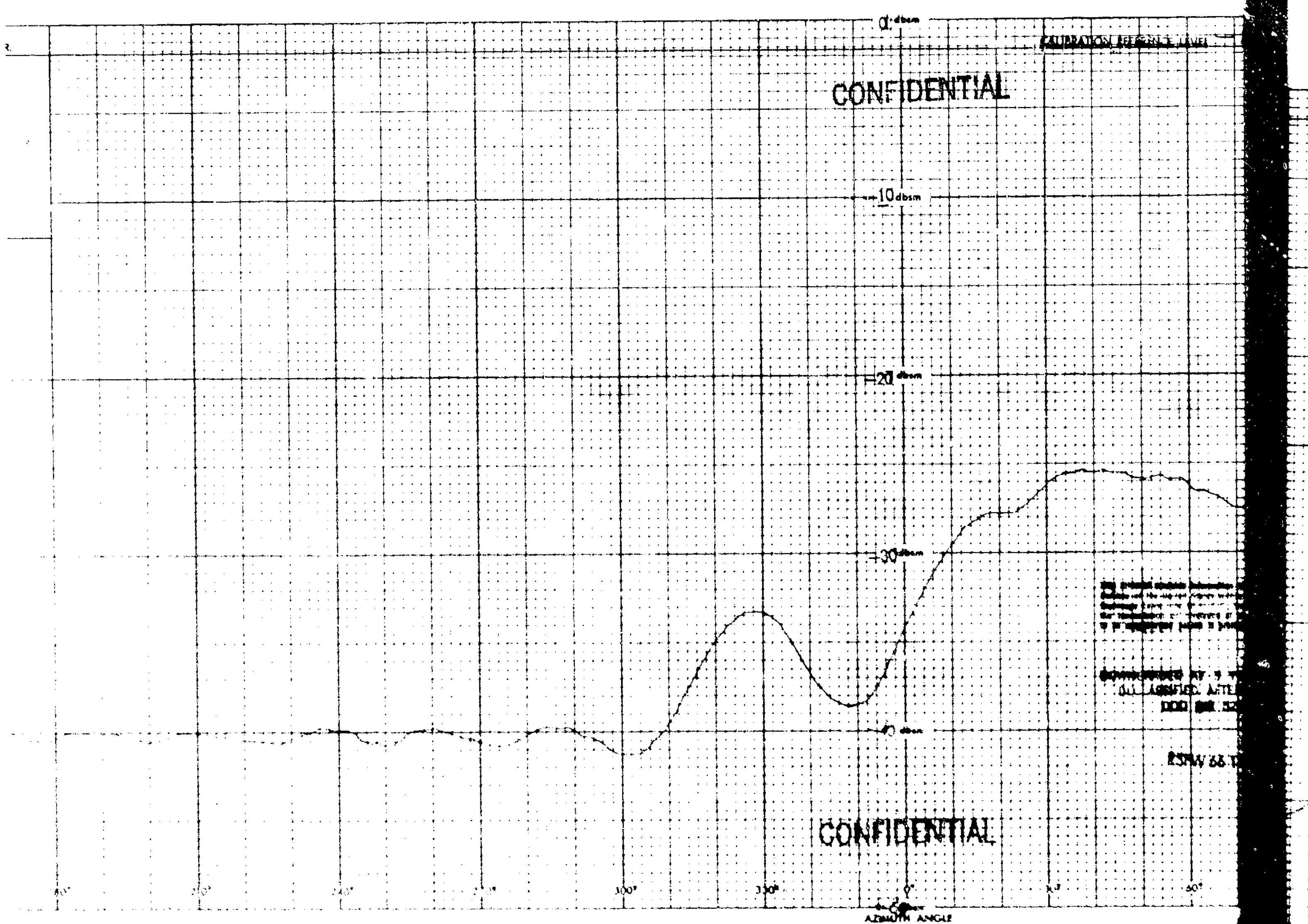
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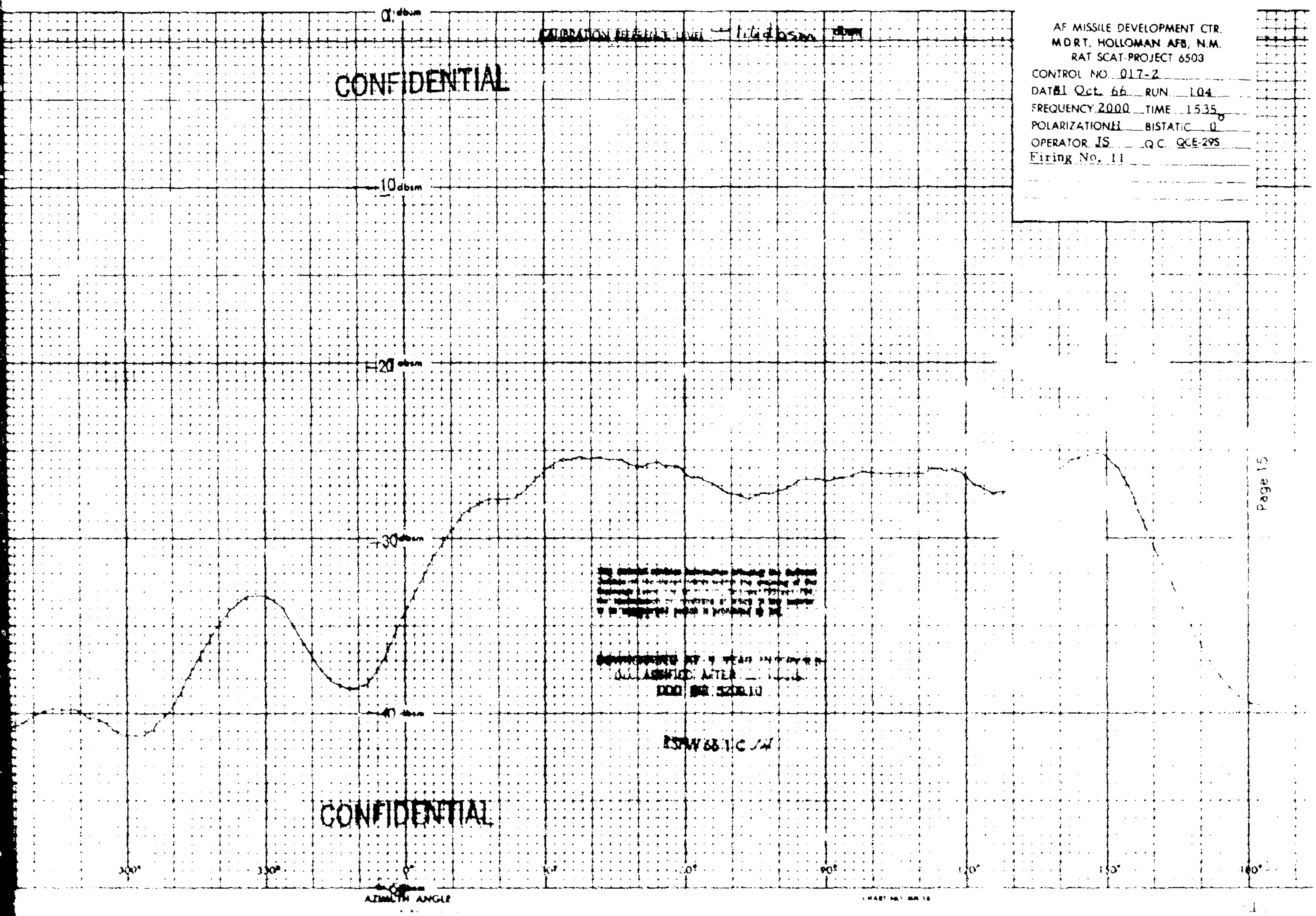

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Page 15

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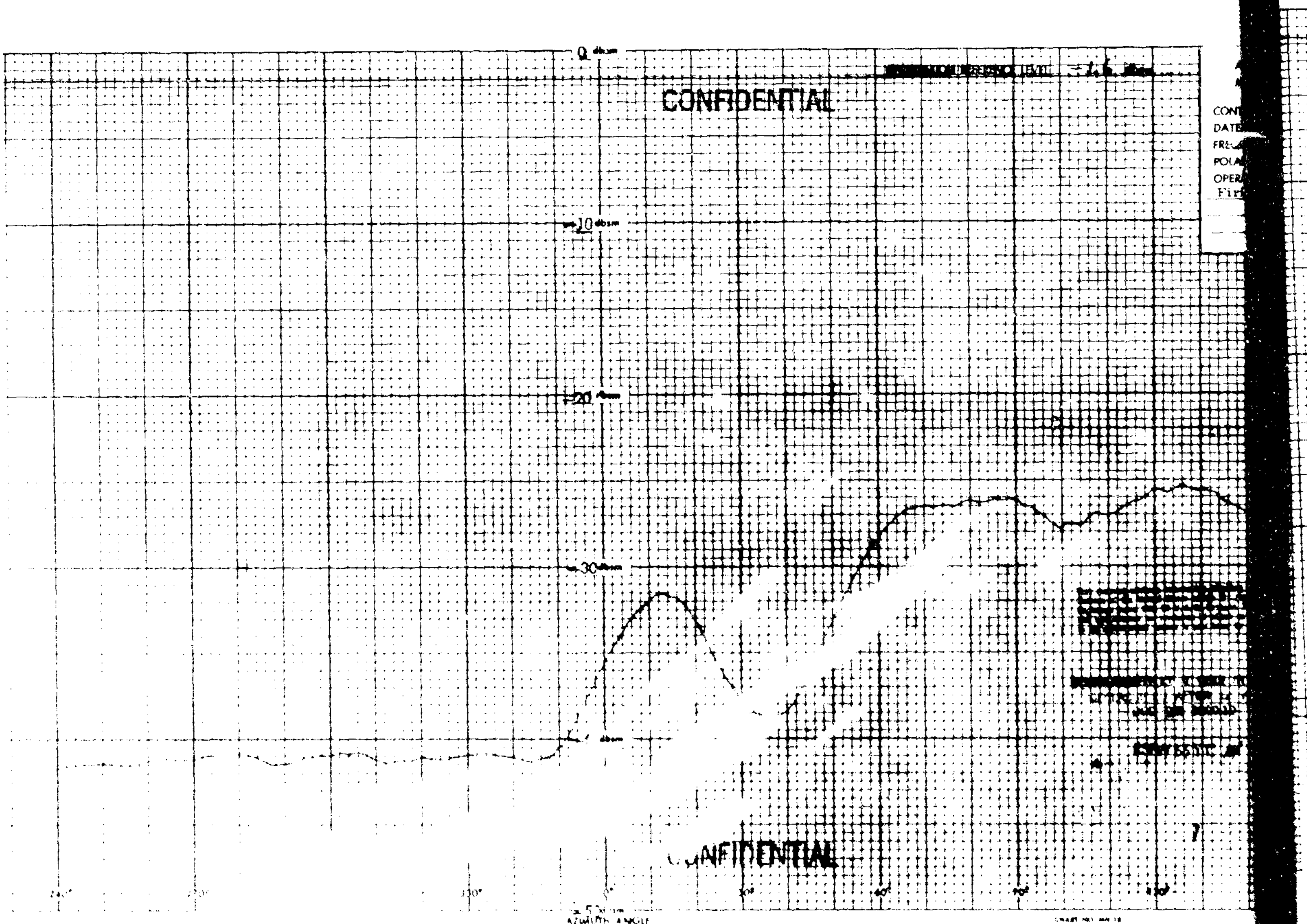
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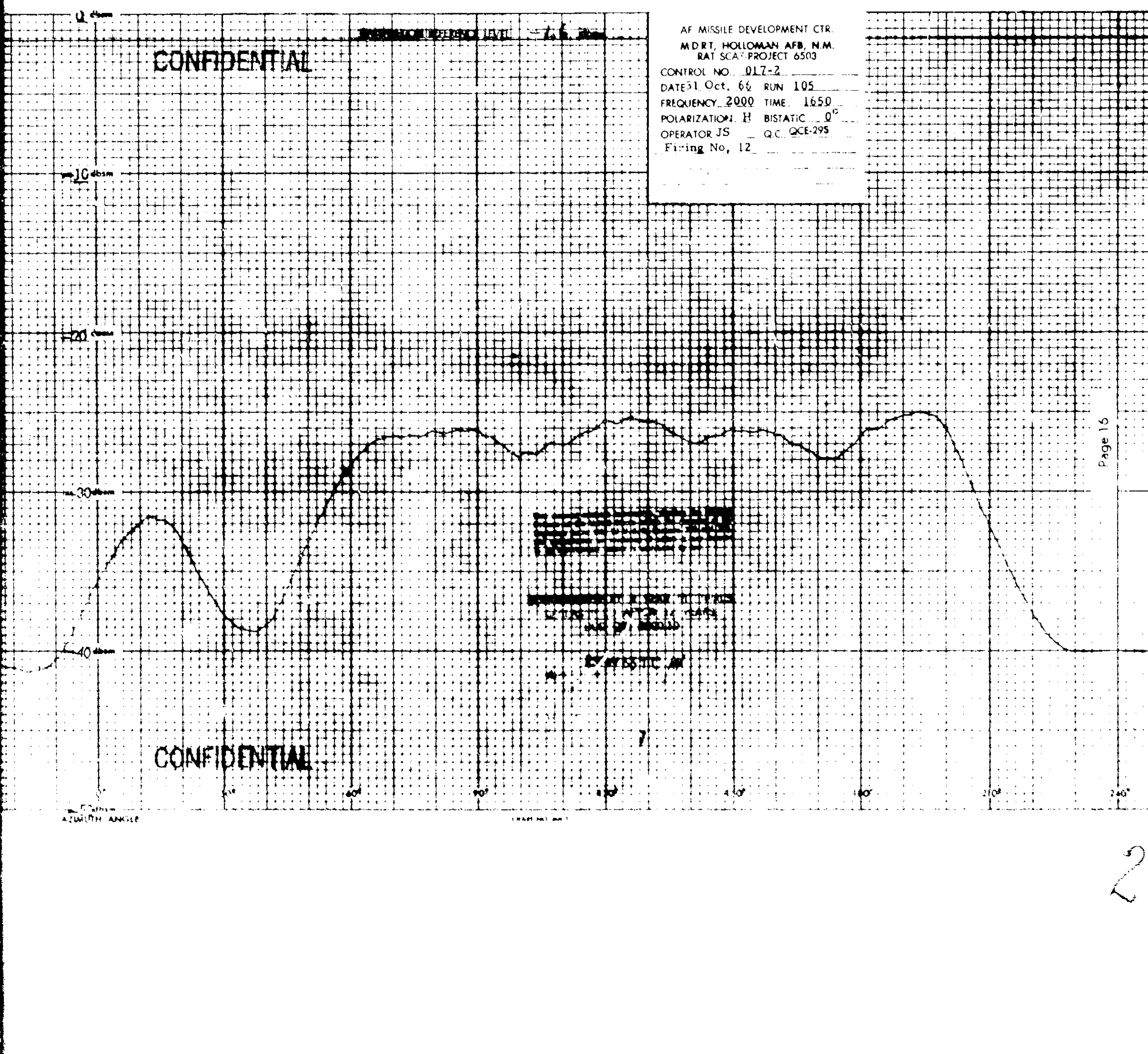
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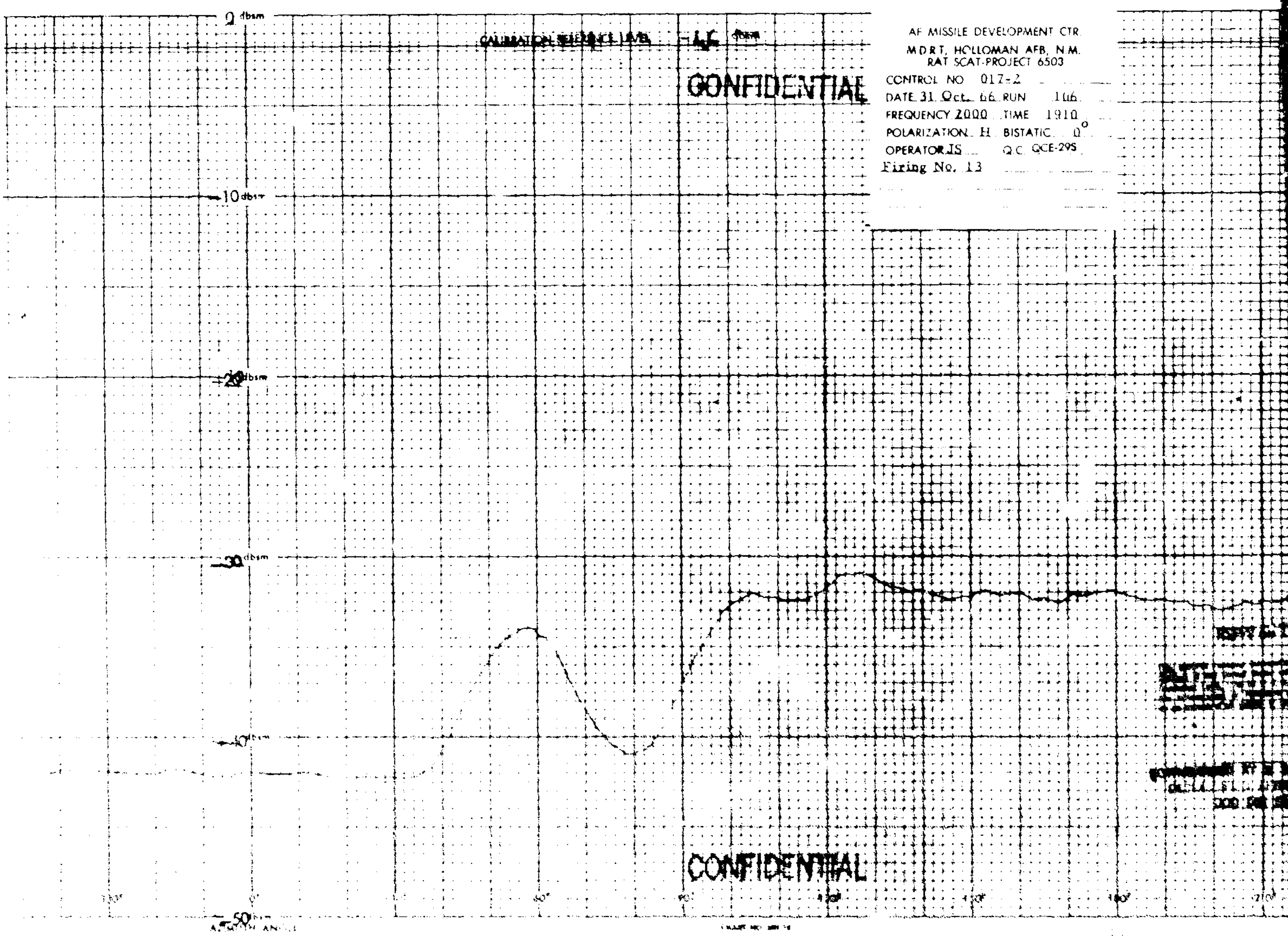
AZIMUTH ANGLE

2



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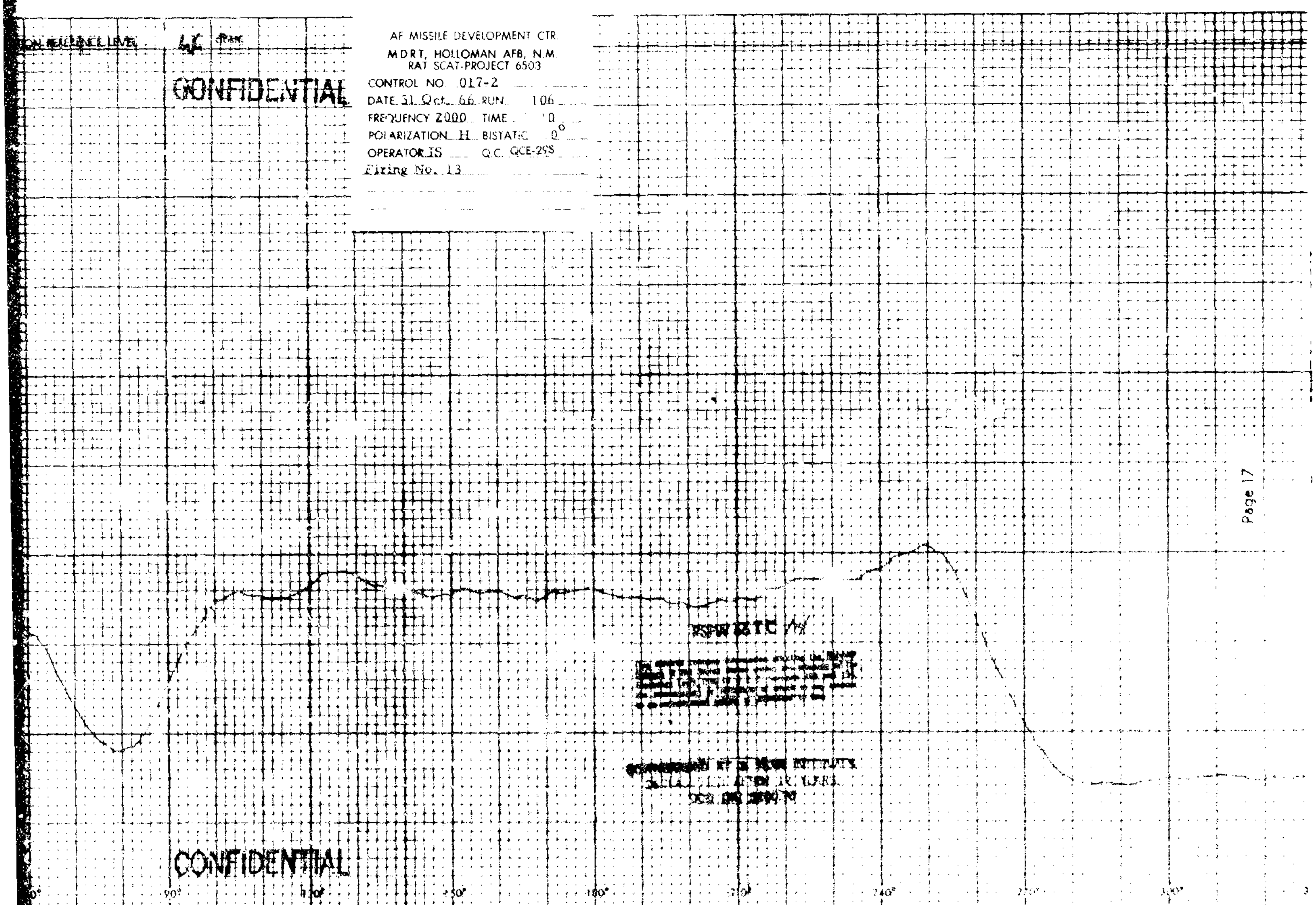
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CONTROL NO. 017-2
DATE 31 Oct. 66 RUN 106
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OPERATOR IS Q.C. QCE-29S
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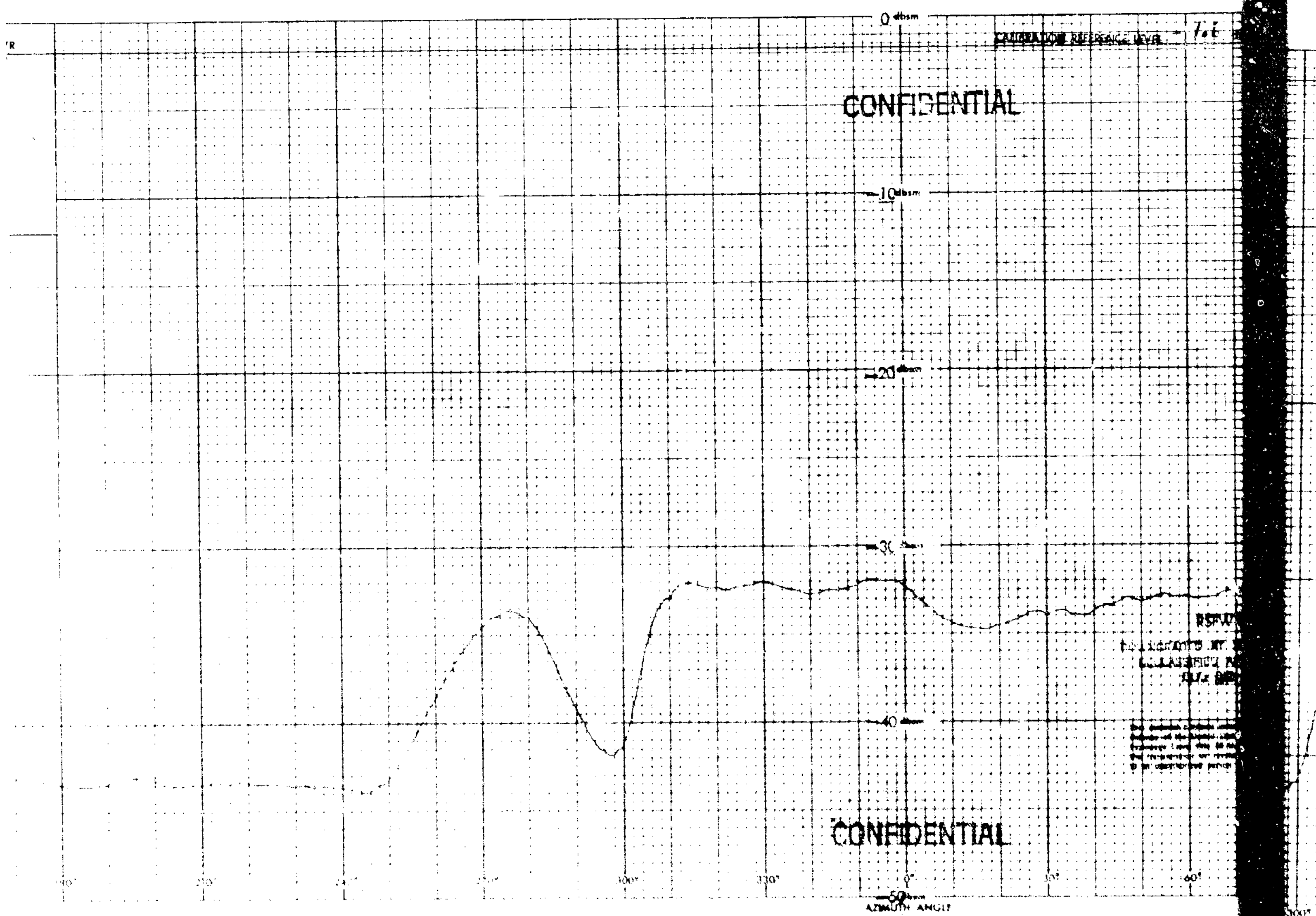
Page 17

2



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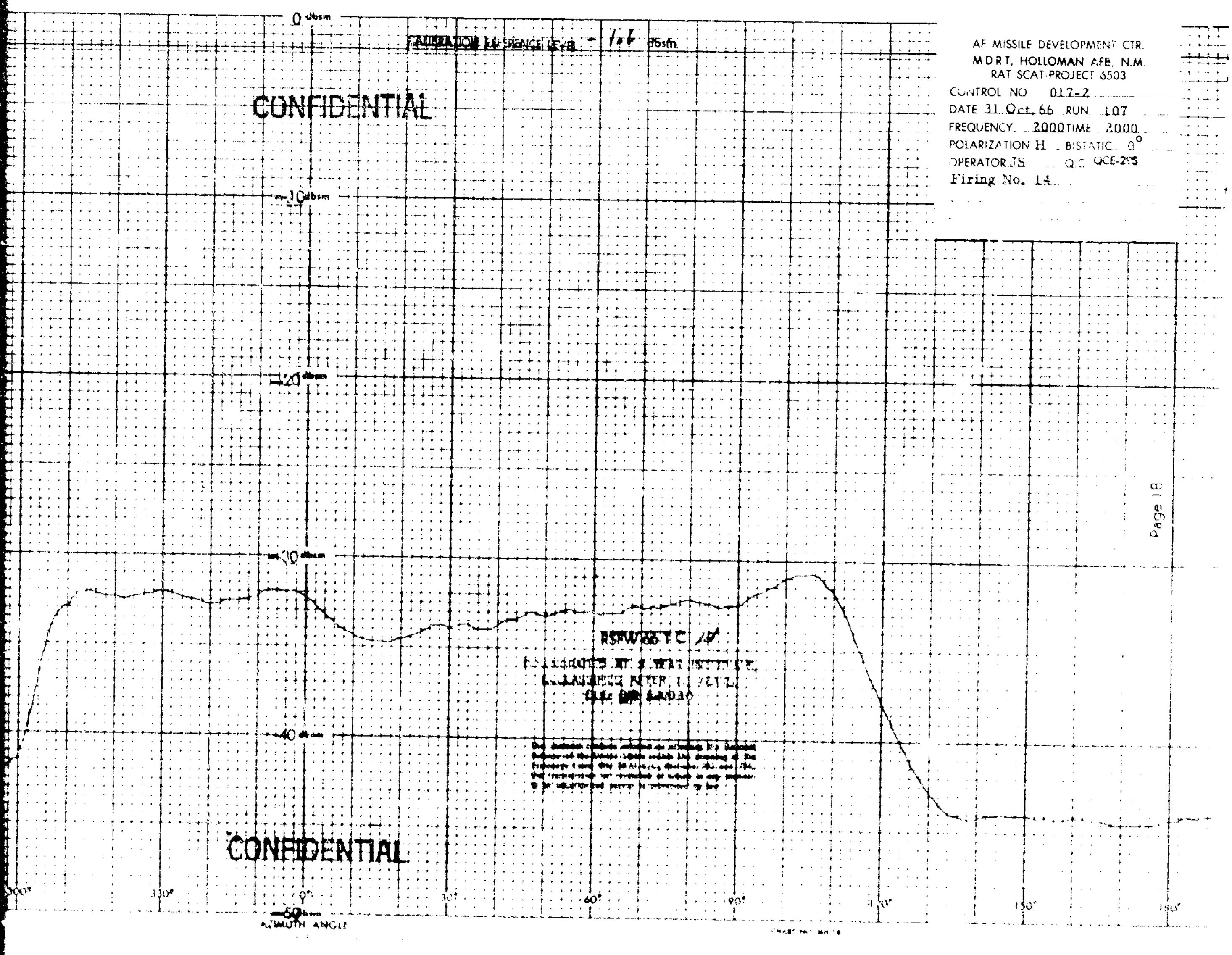

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CONTROL NO. 017-2
DATE 31 Oct. 66 RUN 107
FREQUENCY 2000 TIME 2000
POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-295
Firing No. 14
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Page 18
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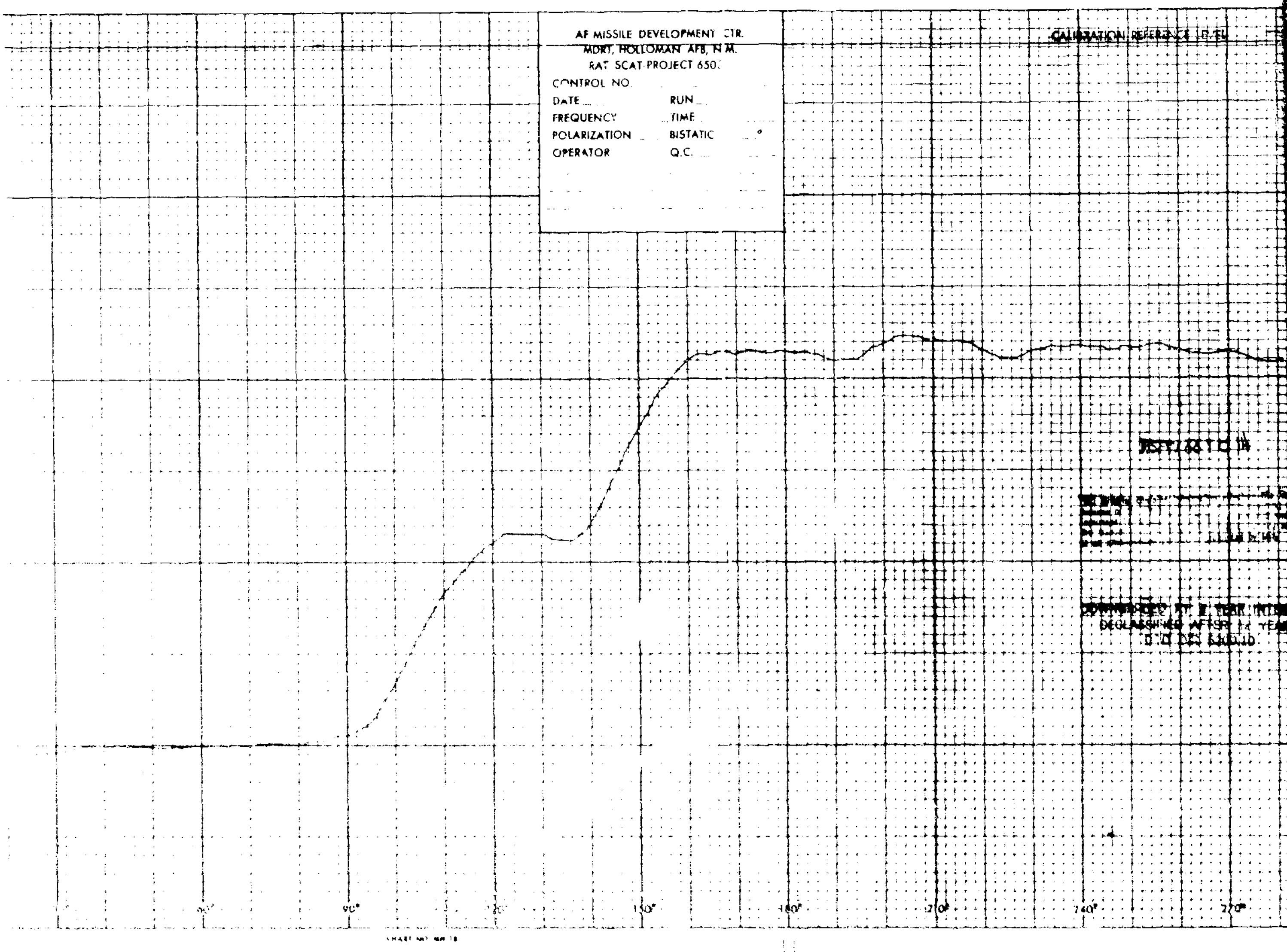
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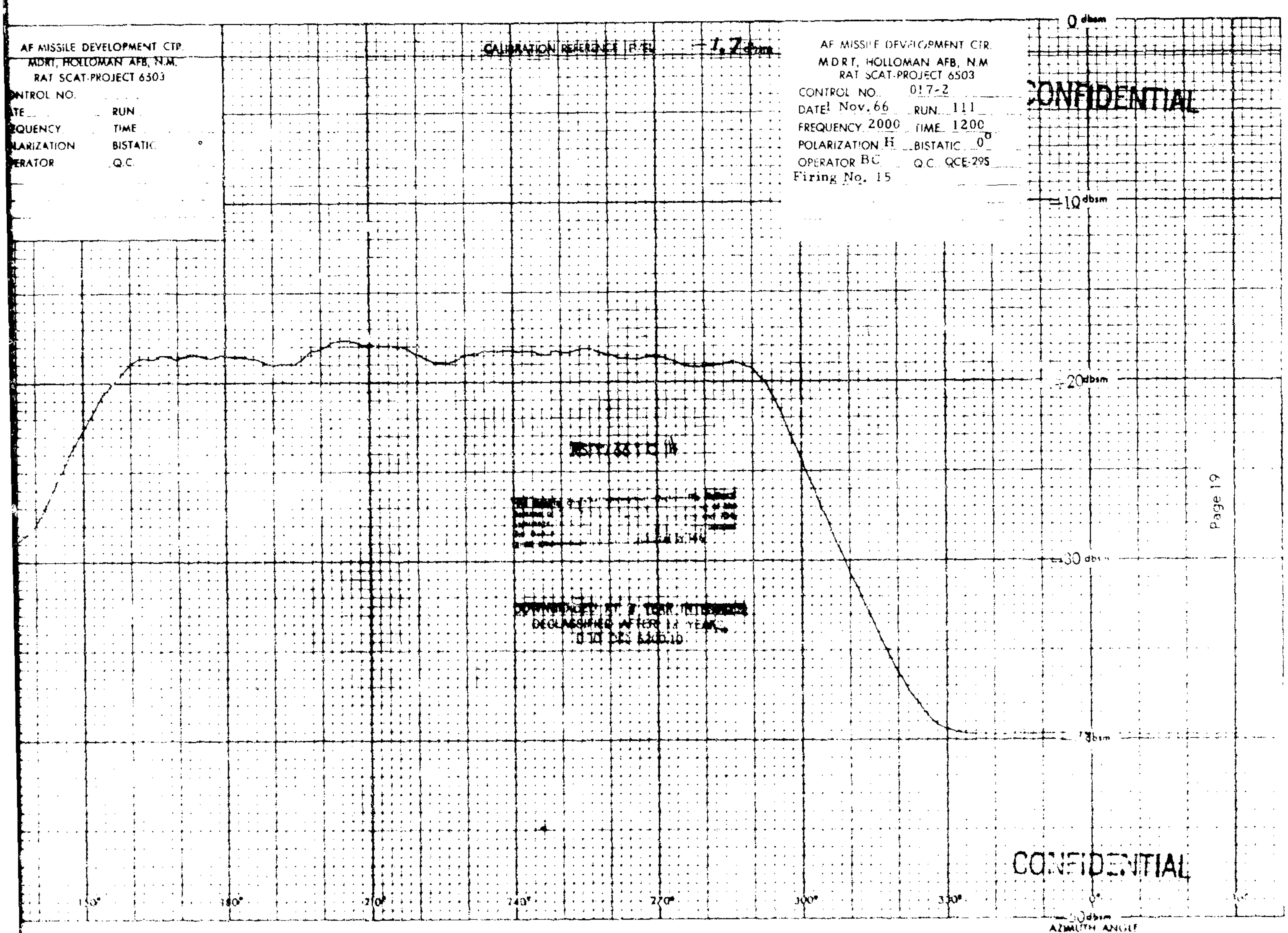

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DATE 1 Nov. 66 RUN 111
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Page 19
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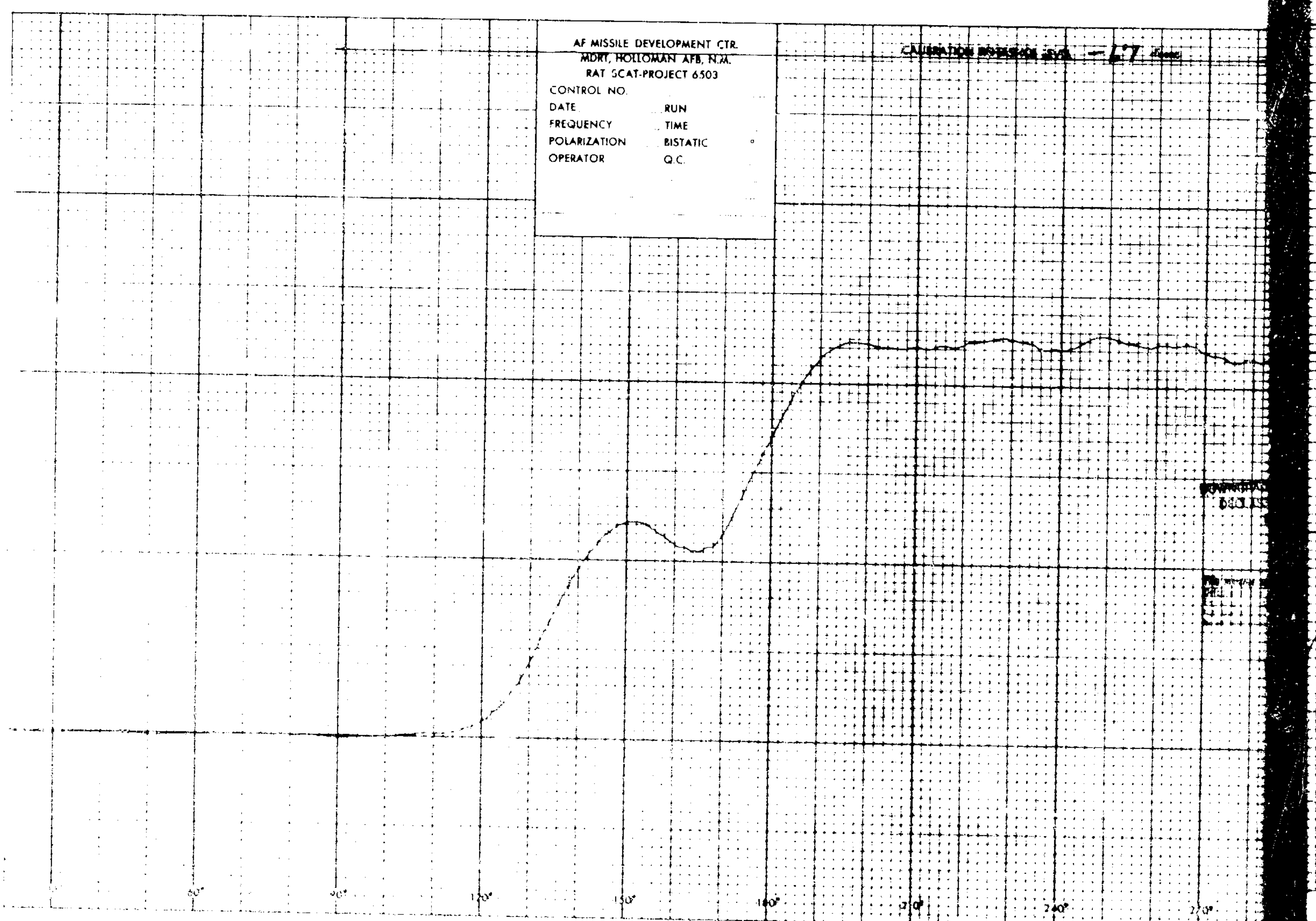
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FREQUENCY
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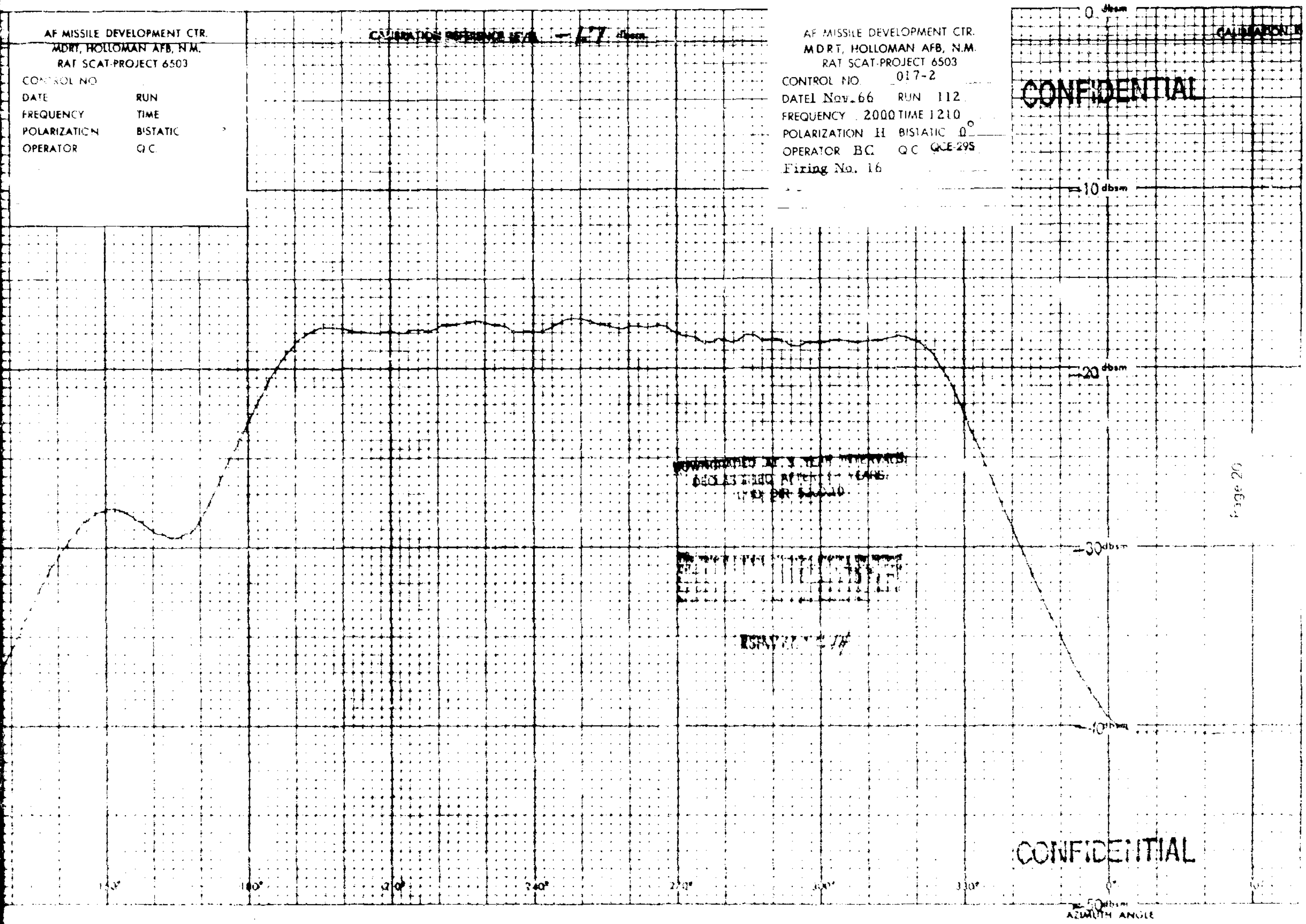
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OPERATOR Q.C.
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M.D.R.T. HOLLOMAN AFB, N.M.
RAT SCAT-PROJECT 6503
CONTROL NO. 017-2
DATE 1 Nov. 66 RUN 112
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OPERATOR B.C. Q.C. QCE-295
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AZIMUTH ANGLE
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Page 20

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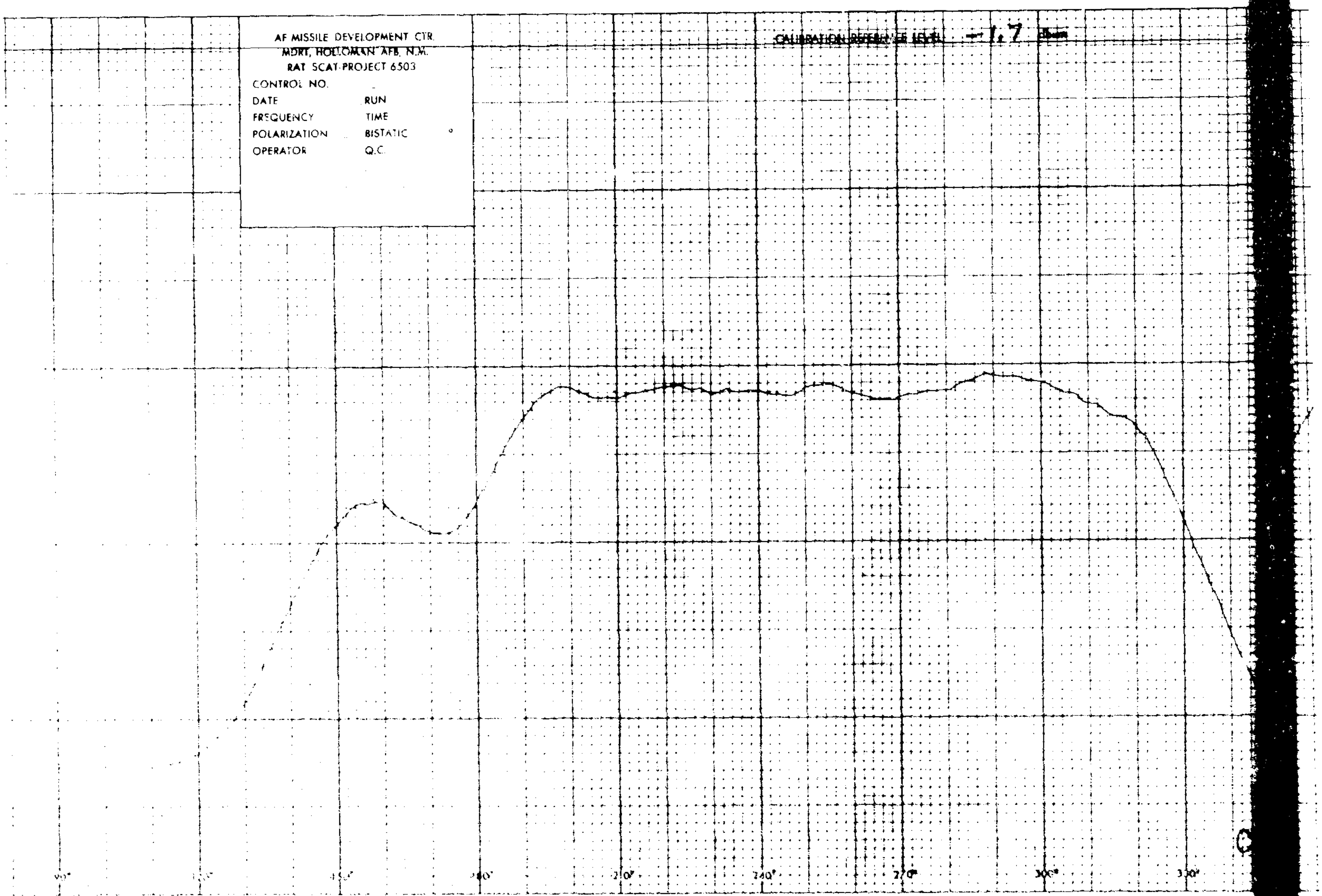
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DATE
RUN
FREQUENCY
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POLARIZATION
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OPERATOR
Q.C.
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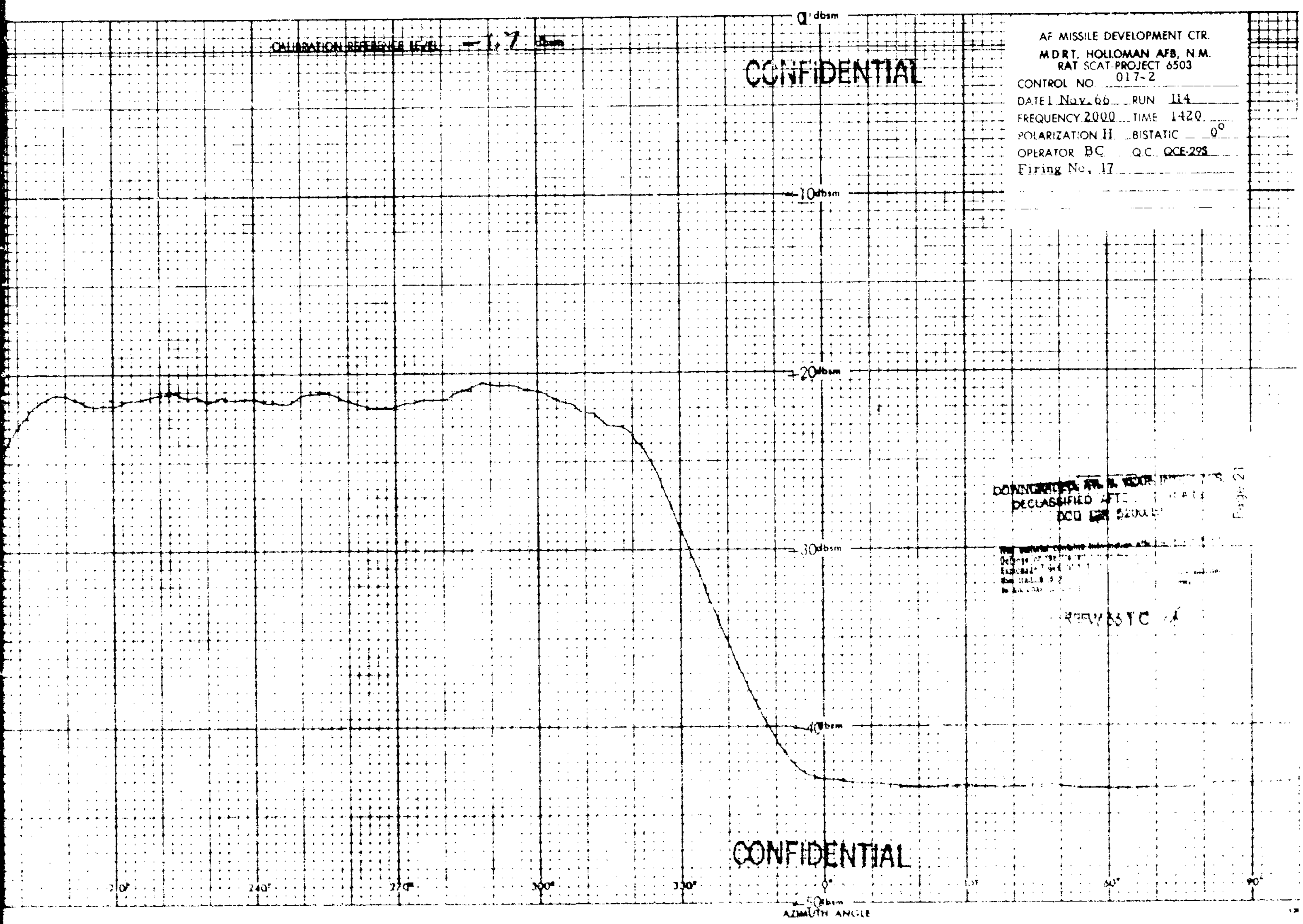
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CONTROL NO. 017-2
DATE 1 Nov. 66 RUN 114
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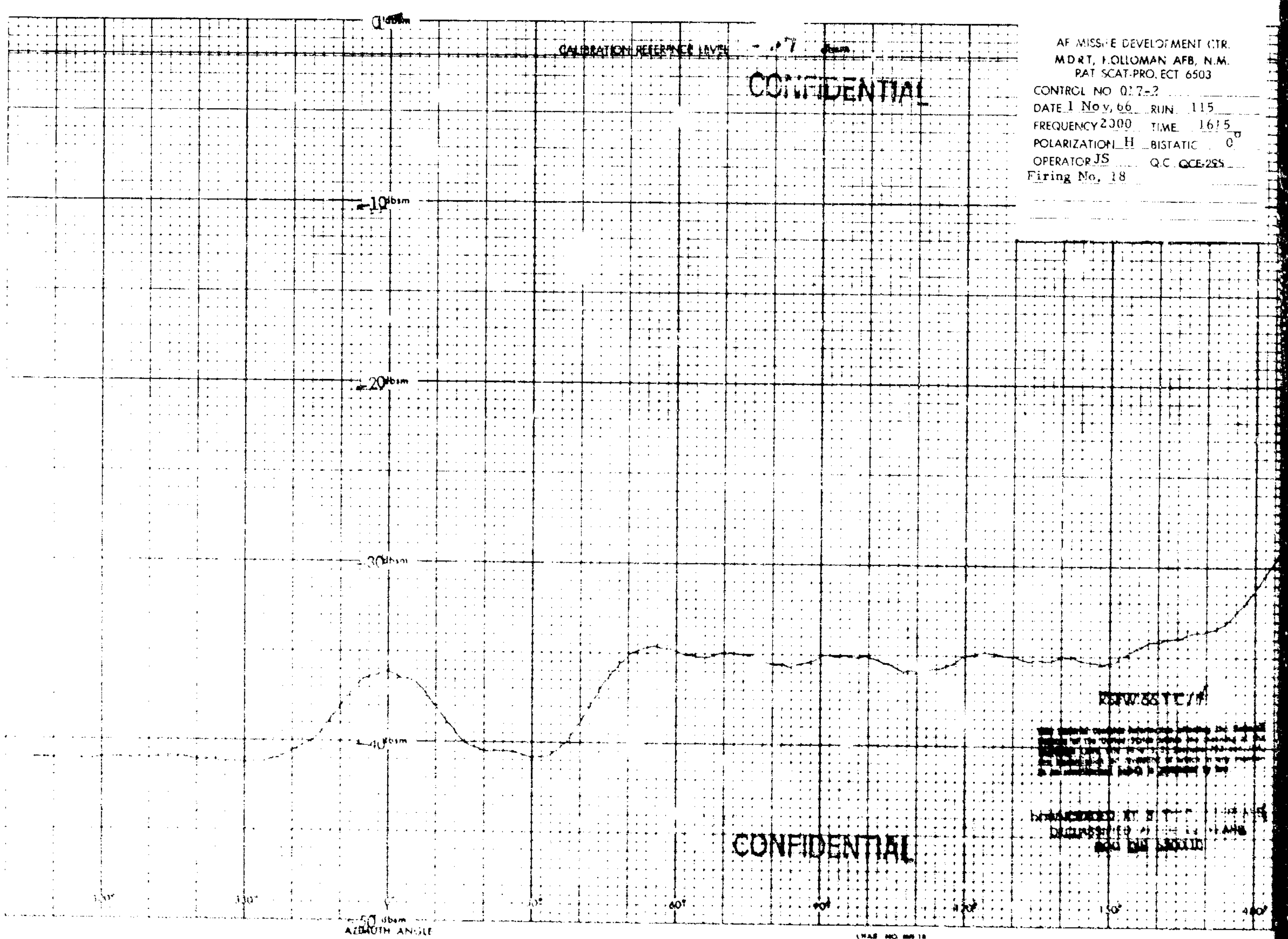
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CONTROL NO 017-2
DATE 1 Nov, 66 RUN 115
FREQUENCY 2000 TIME 1615
POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-255
Firing No, 18
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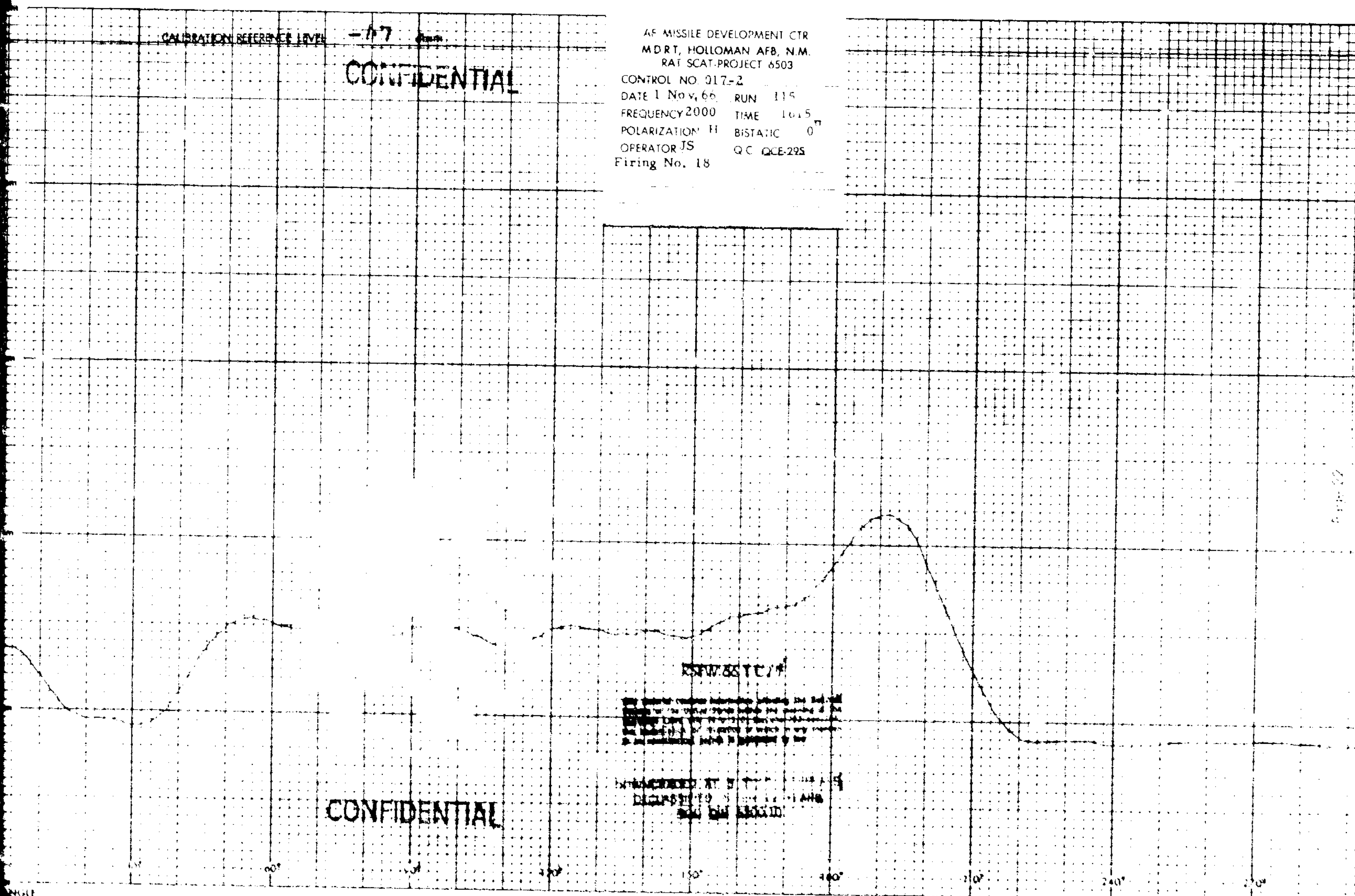
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RUN 115
FREQUENCY 2000
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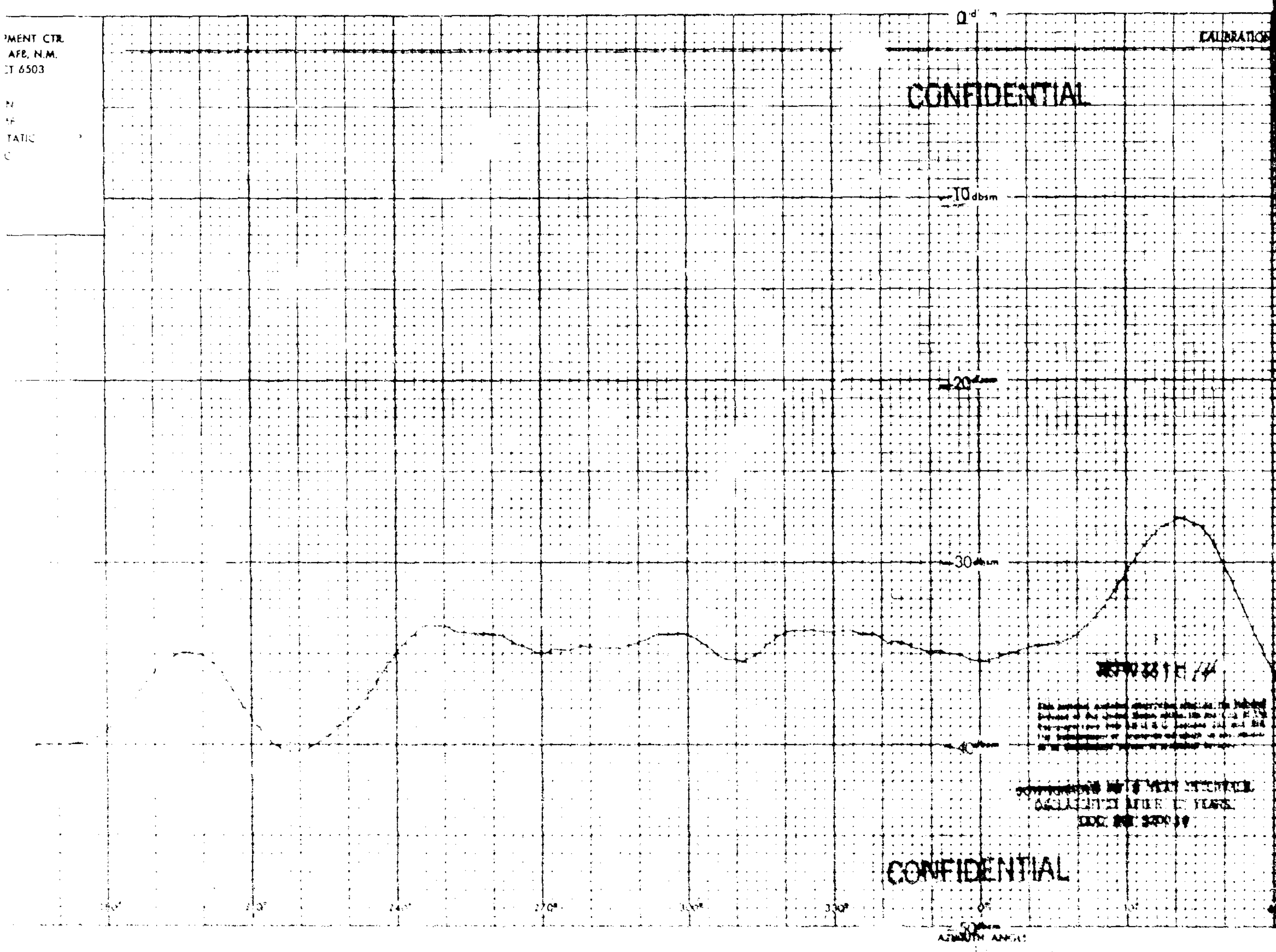

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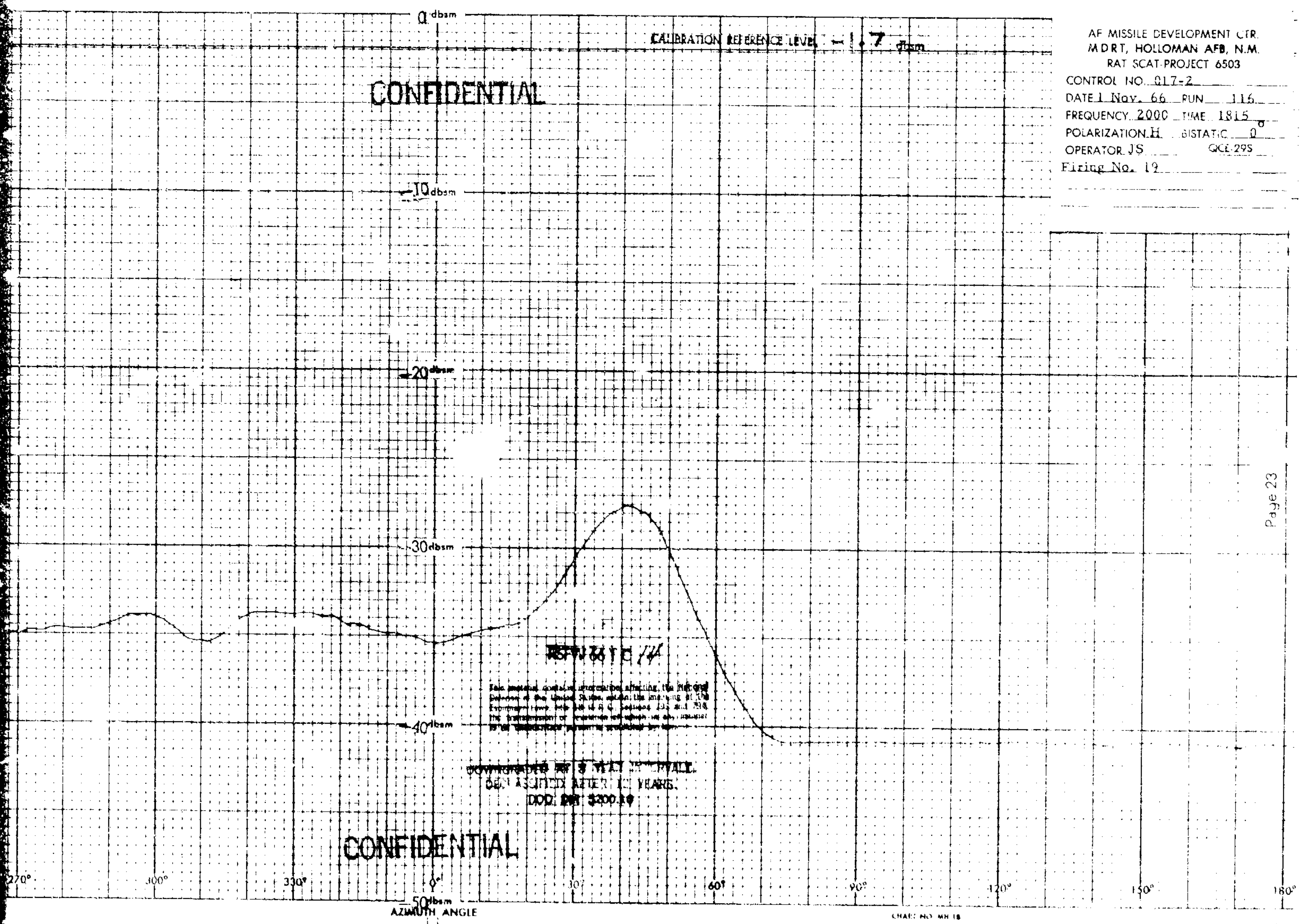
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CONTROL NO. 017-2
DATE 1 Nov. 66 RUN 116
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OPERATOR JS QCE-295
Firing No. 19
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Page 23
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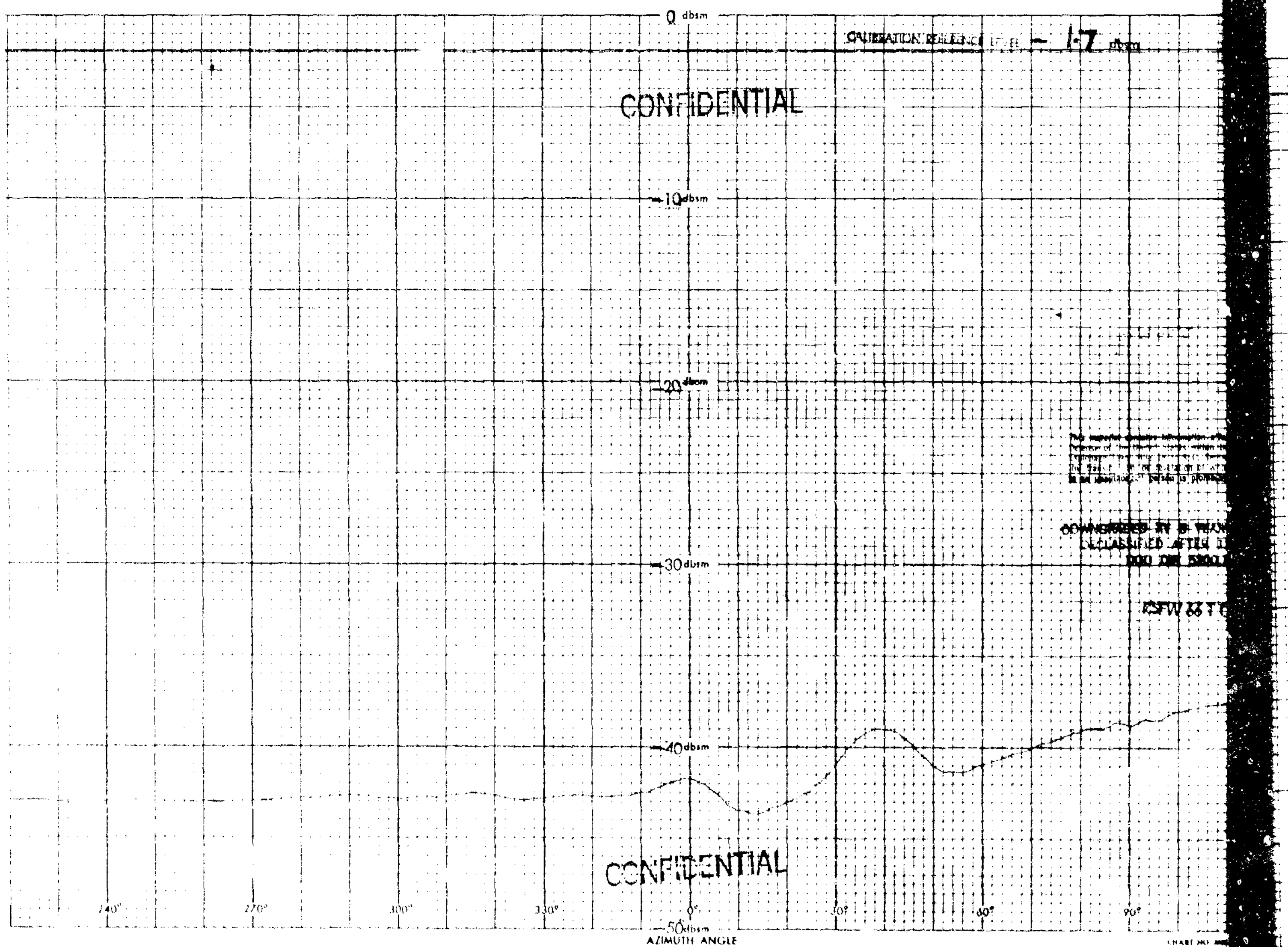
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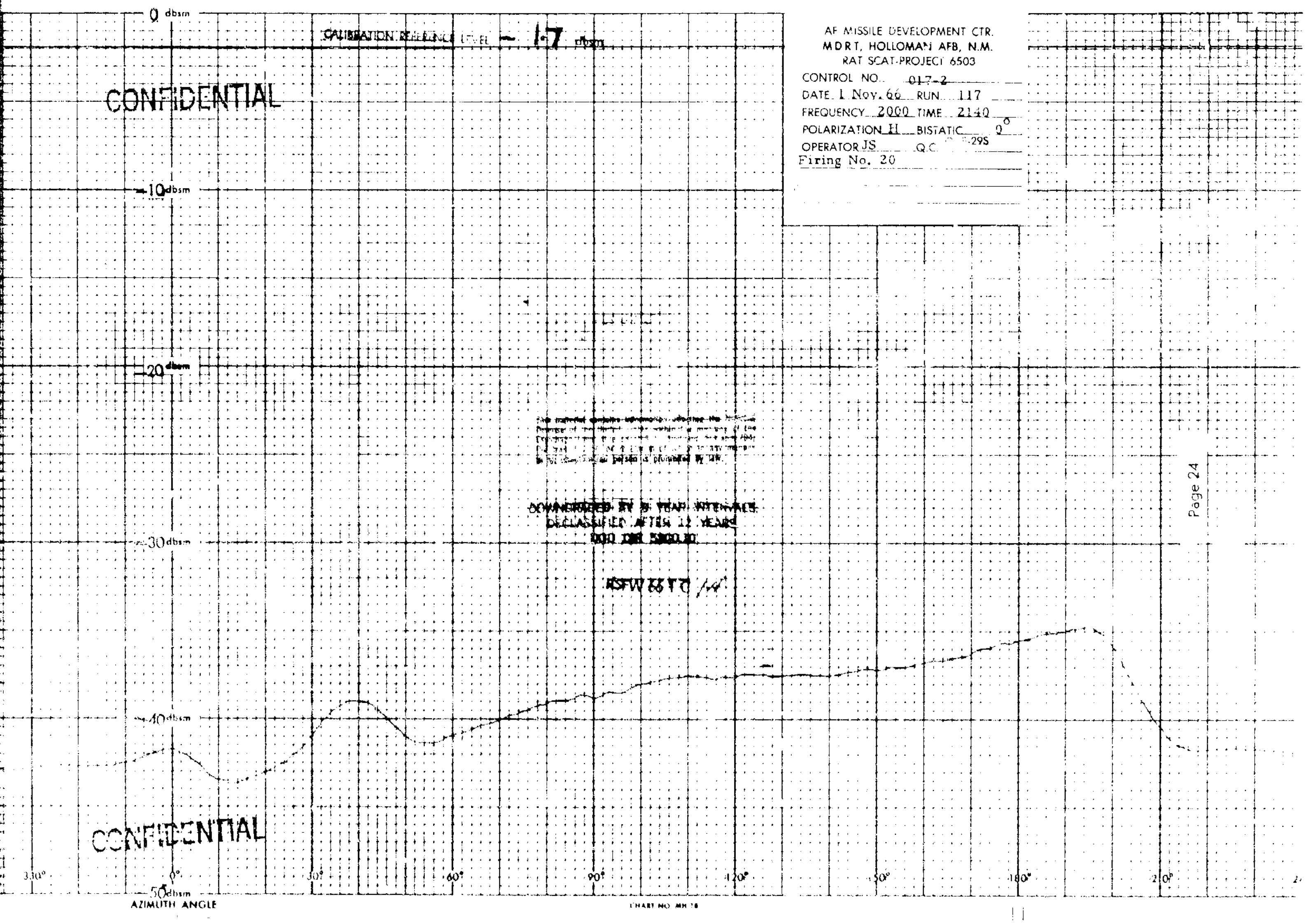

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CONTROL NO. 017-2
DATE 1 Nov. 66 RUN 117
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OPERATOR JS Q.C.
Firing No. 20
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DOD DIR 5200.10
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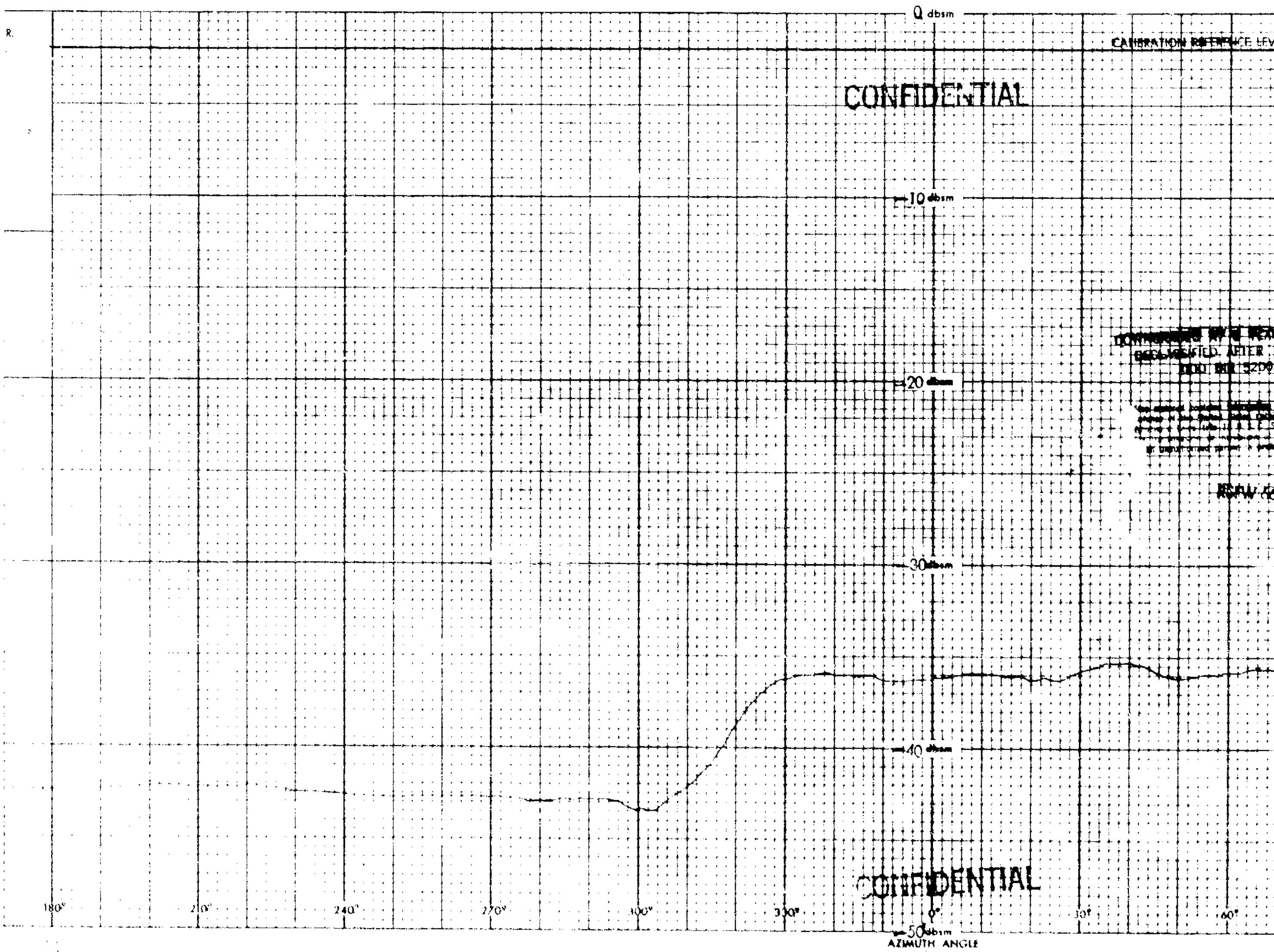
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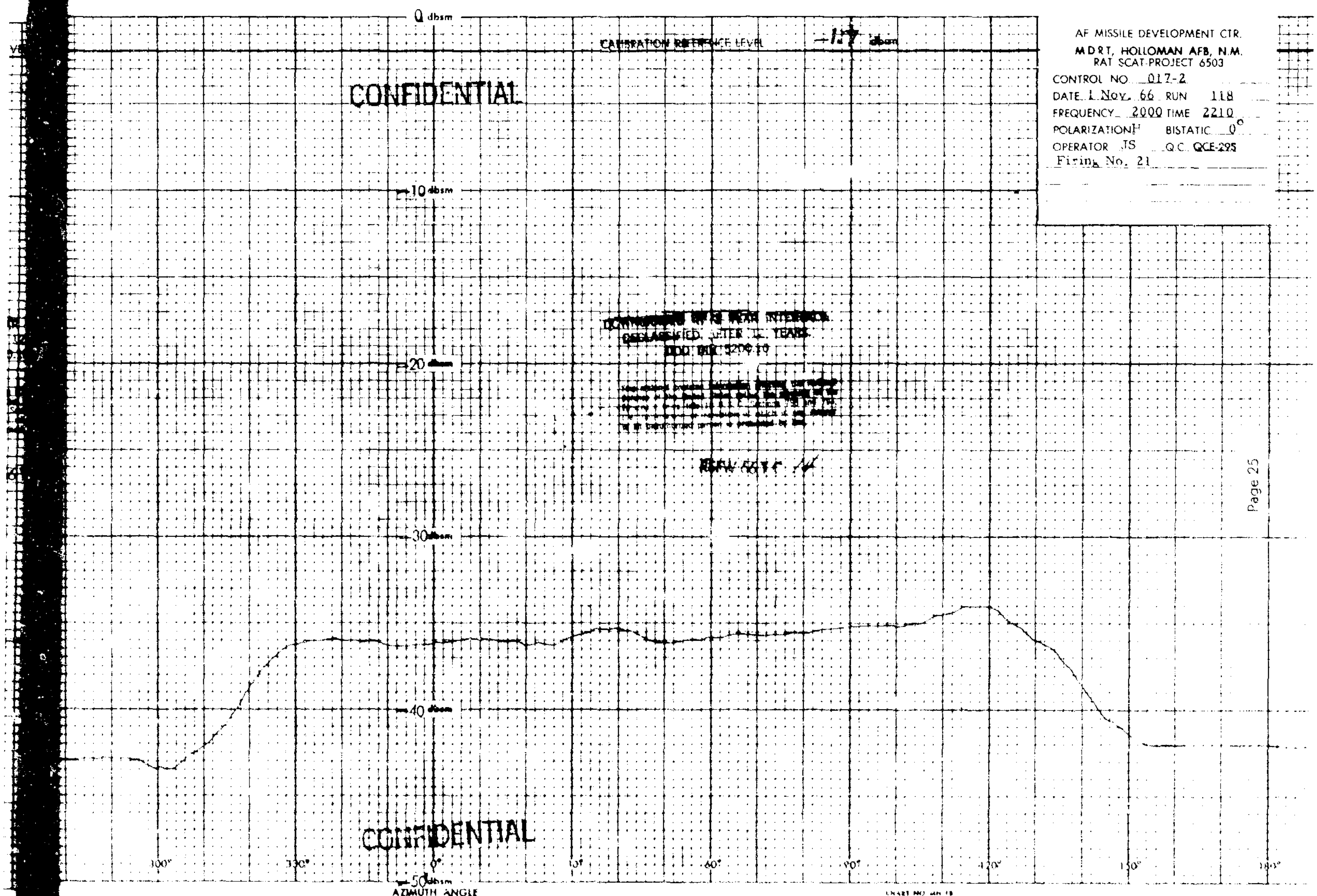
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CONTROL NO. 017-2
DATE 1 Nov. 66 RUN 118
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OPERATOR JS Q.C. QCE-295
Firing No. 21
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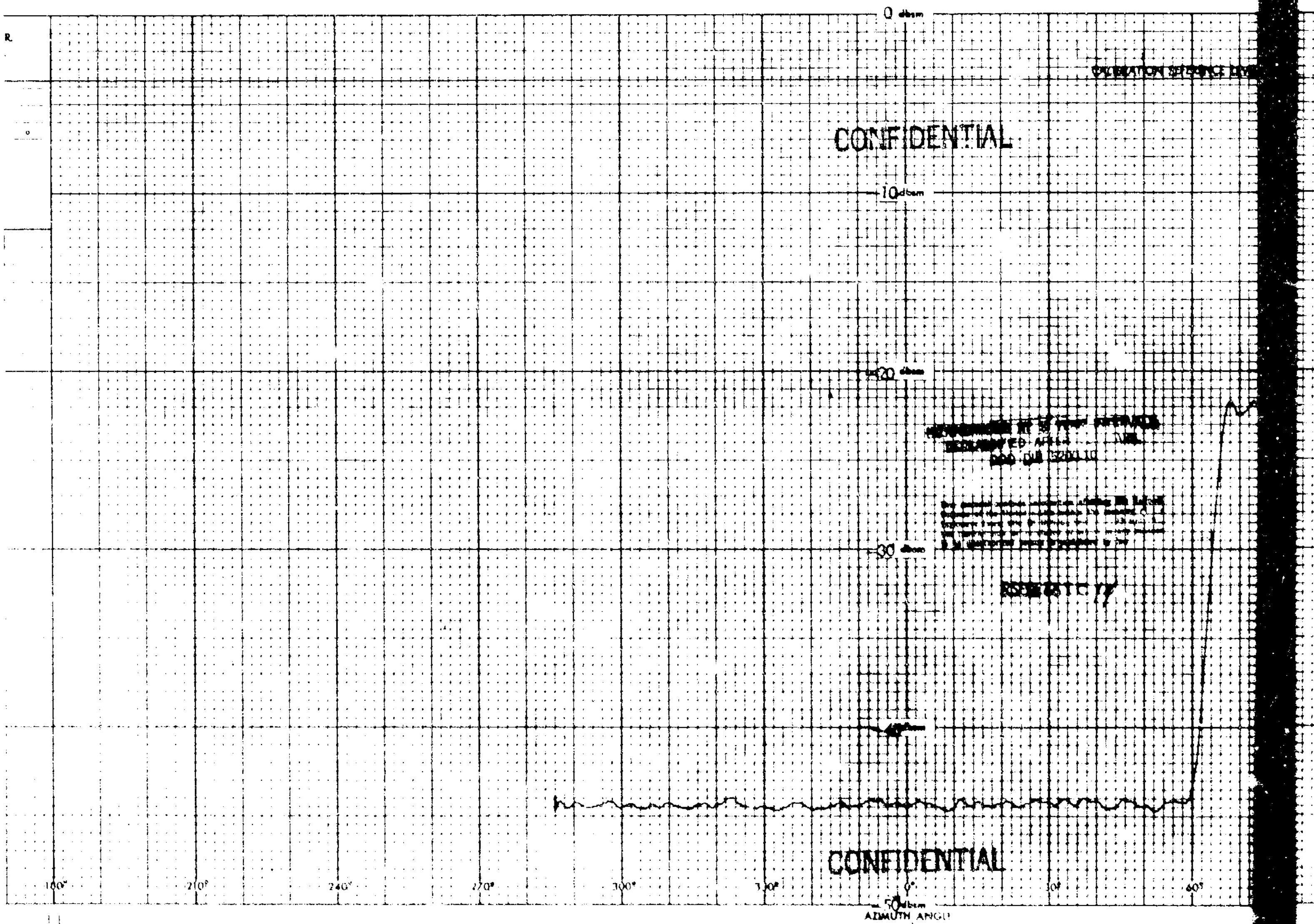

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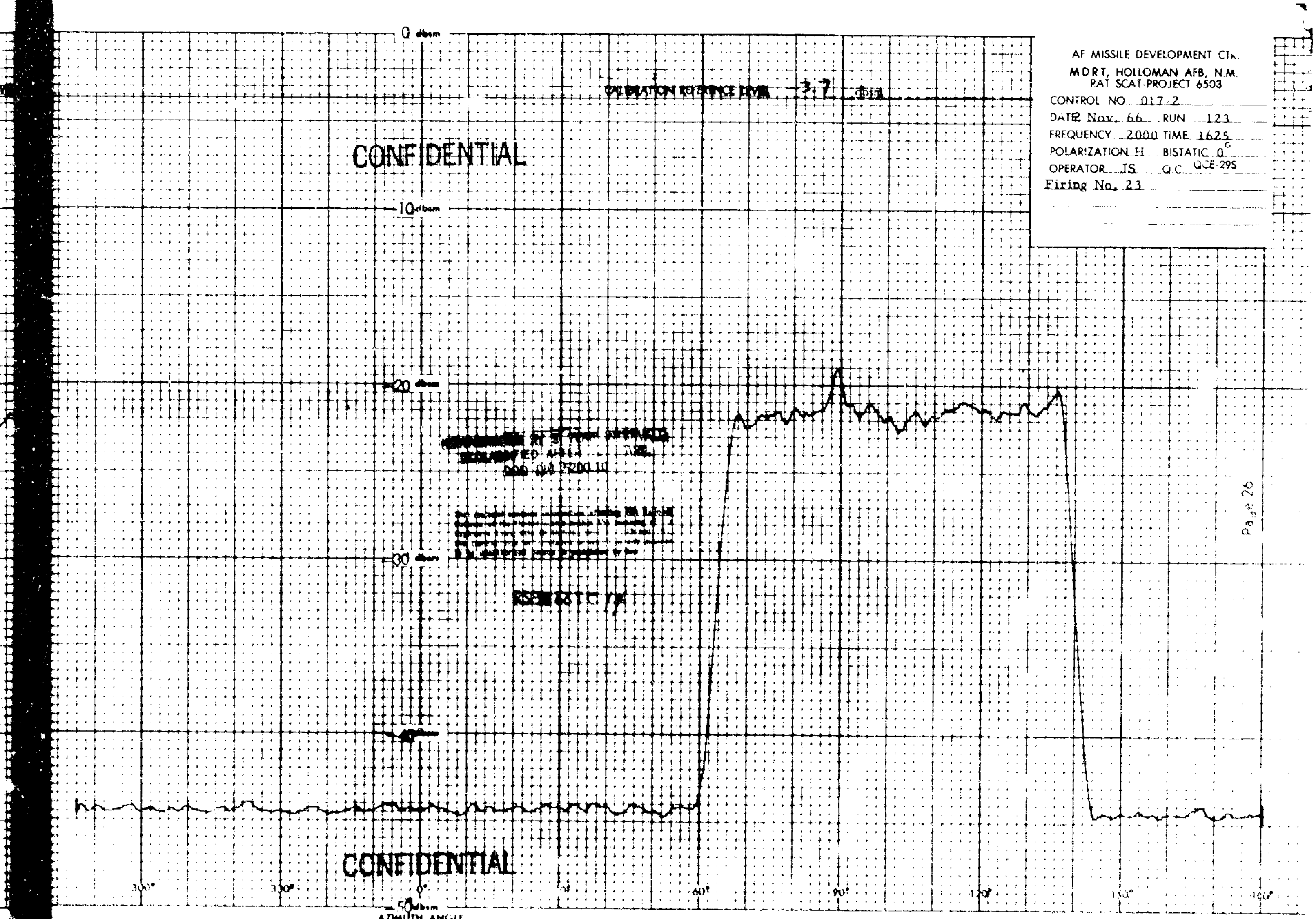

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CONTROL NO. 017-2
DATE 2 Nov. 66 RUN 123
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POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-29S
Firing No. 23
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Page 26
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AZIMUTH ANGLE

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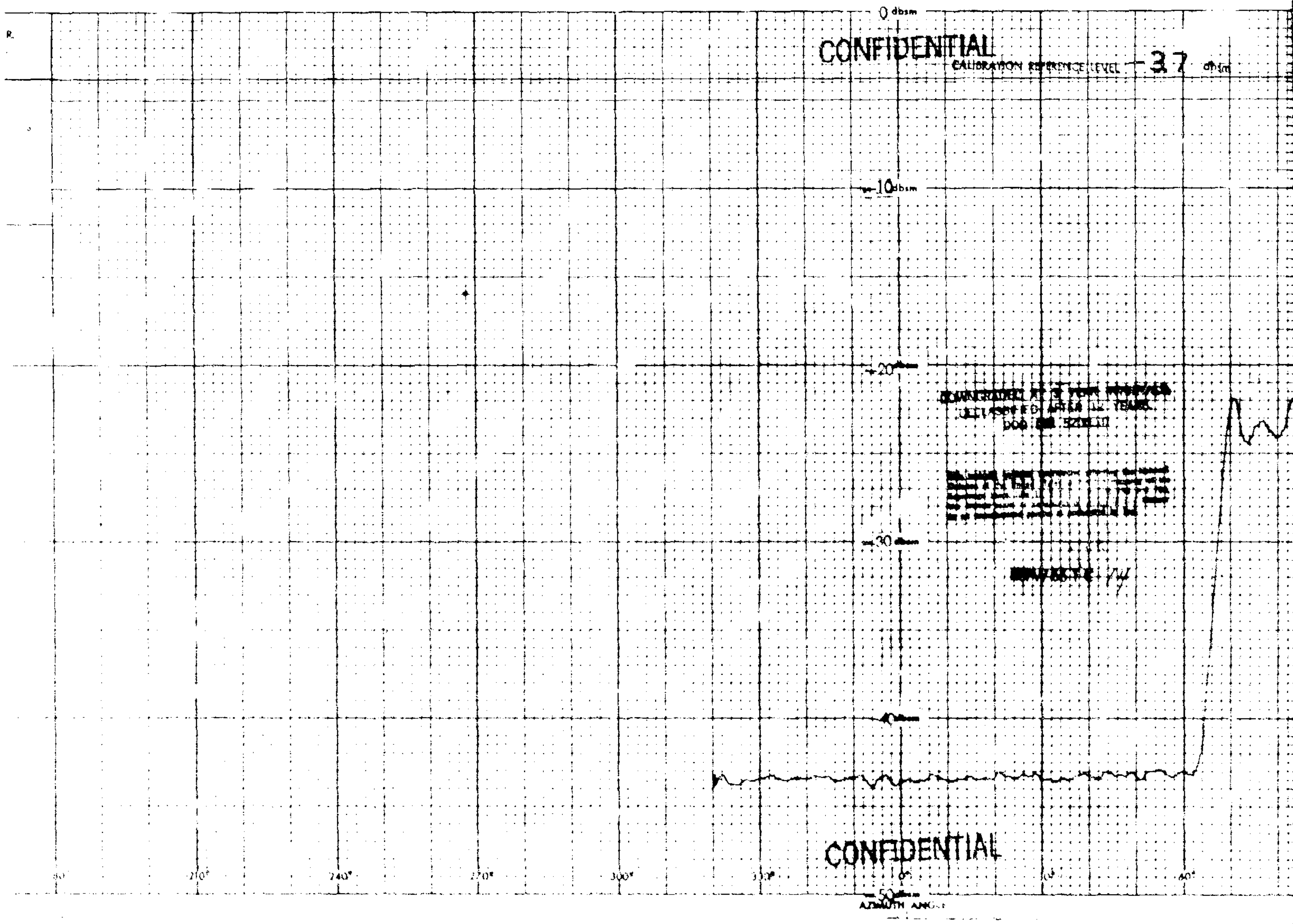
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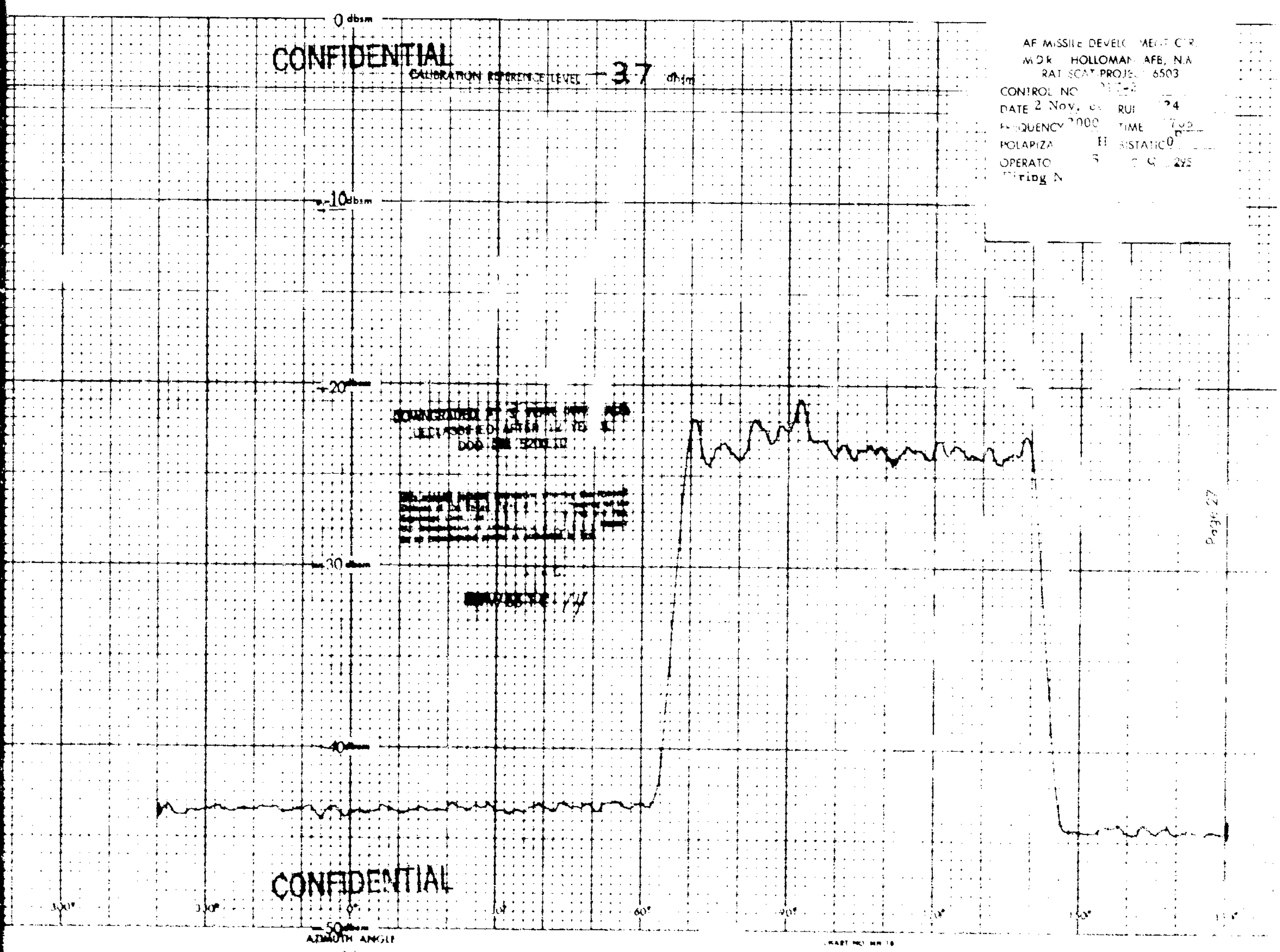

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RAT SCAT PROJECT 6503
CONTROL NO
DATE 2 Nov,
FREQUENCY
TIME
POLARIZA
OPERATO
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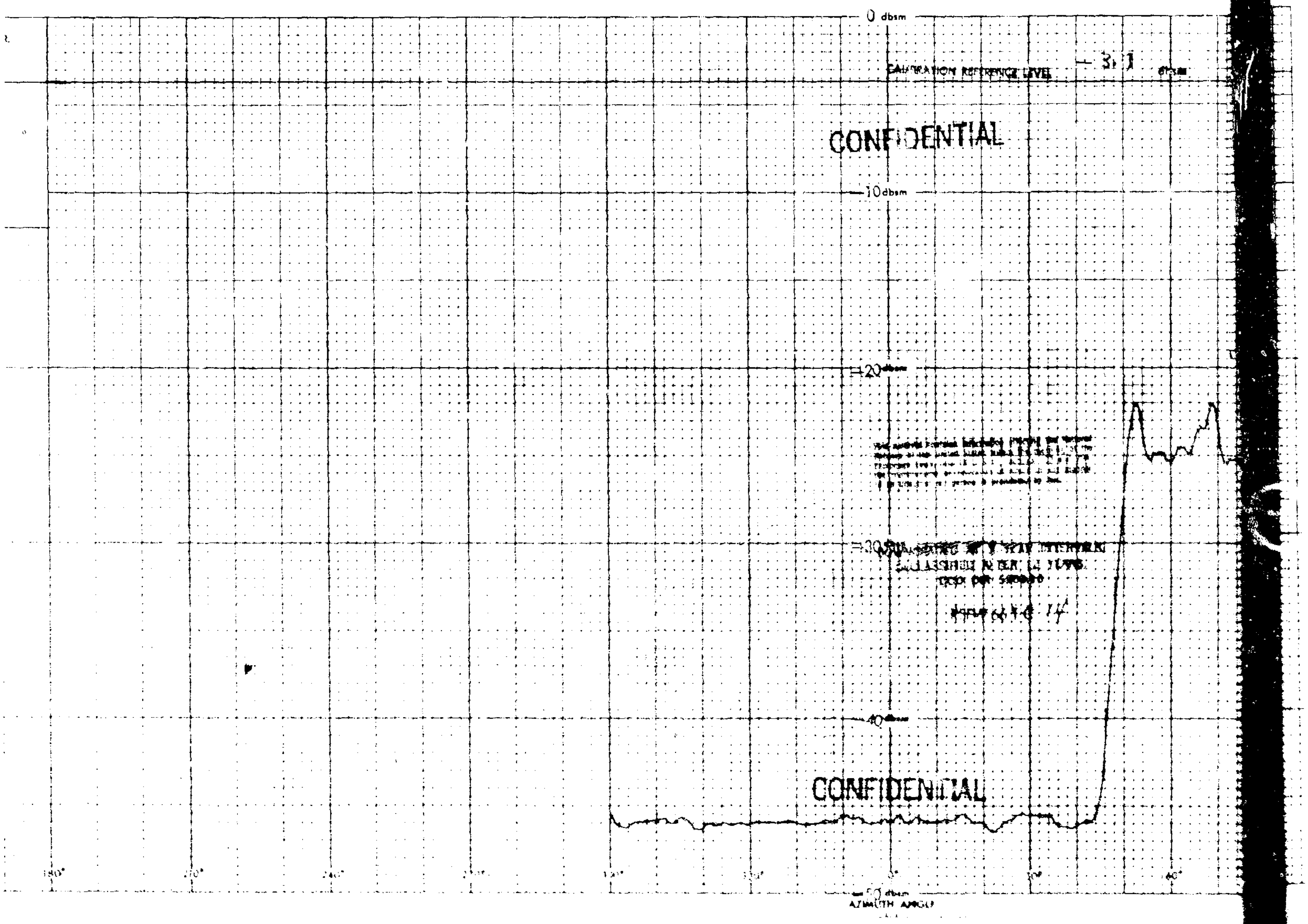

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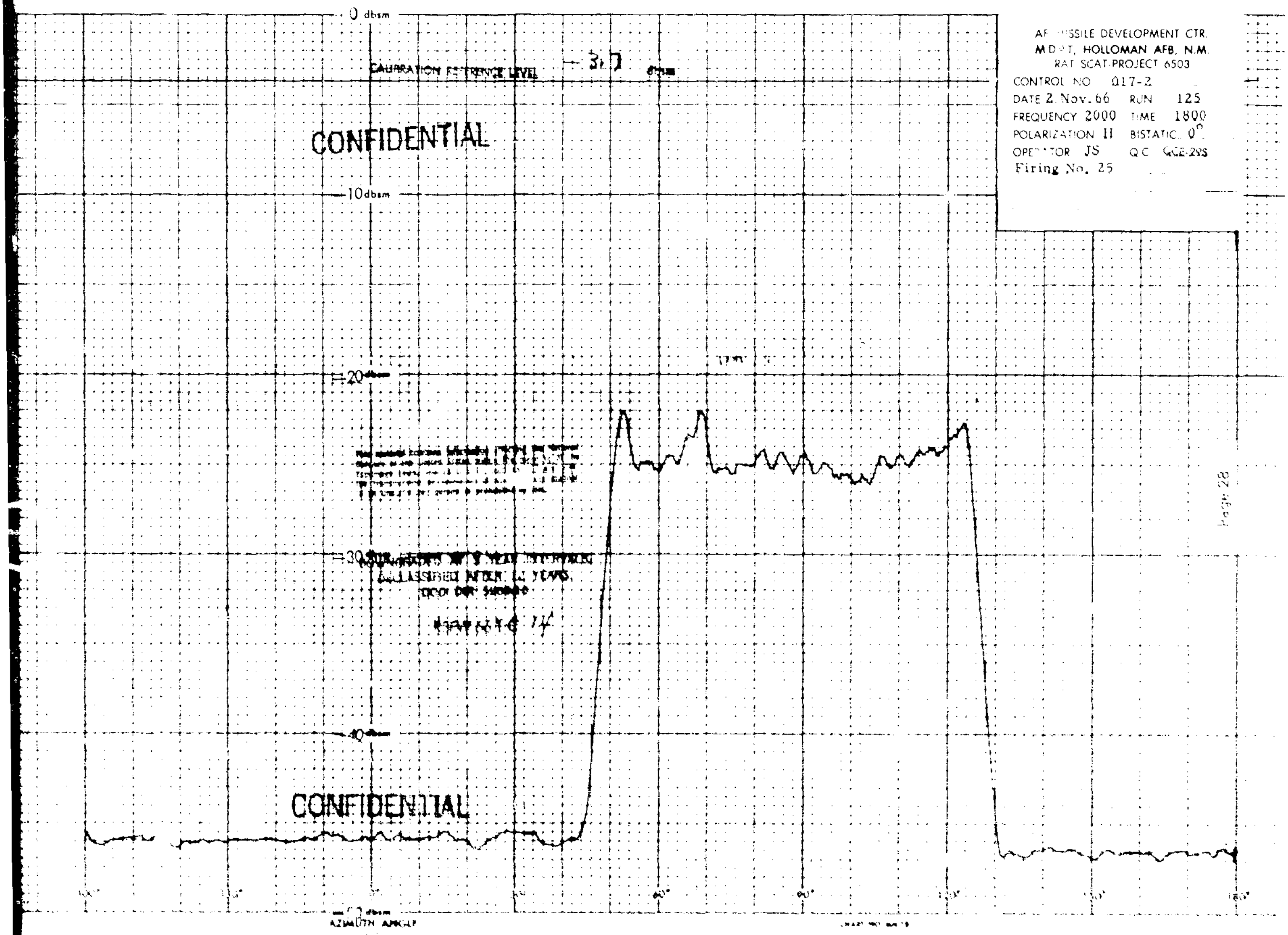
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MDAT, HOLLOMAN AFB, N.M.
RAT SCAT-PROJECT 6503
CONTROL NO 017-2
DATE 2 Nov. 66 RUN 125
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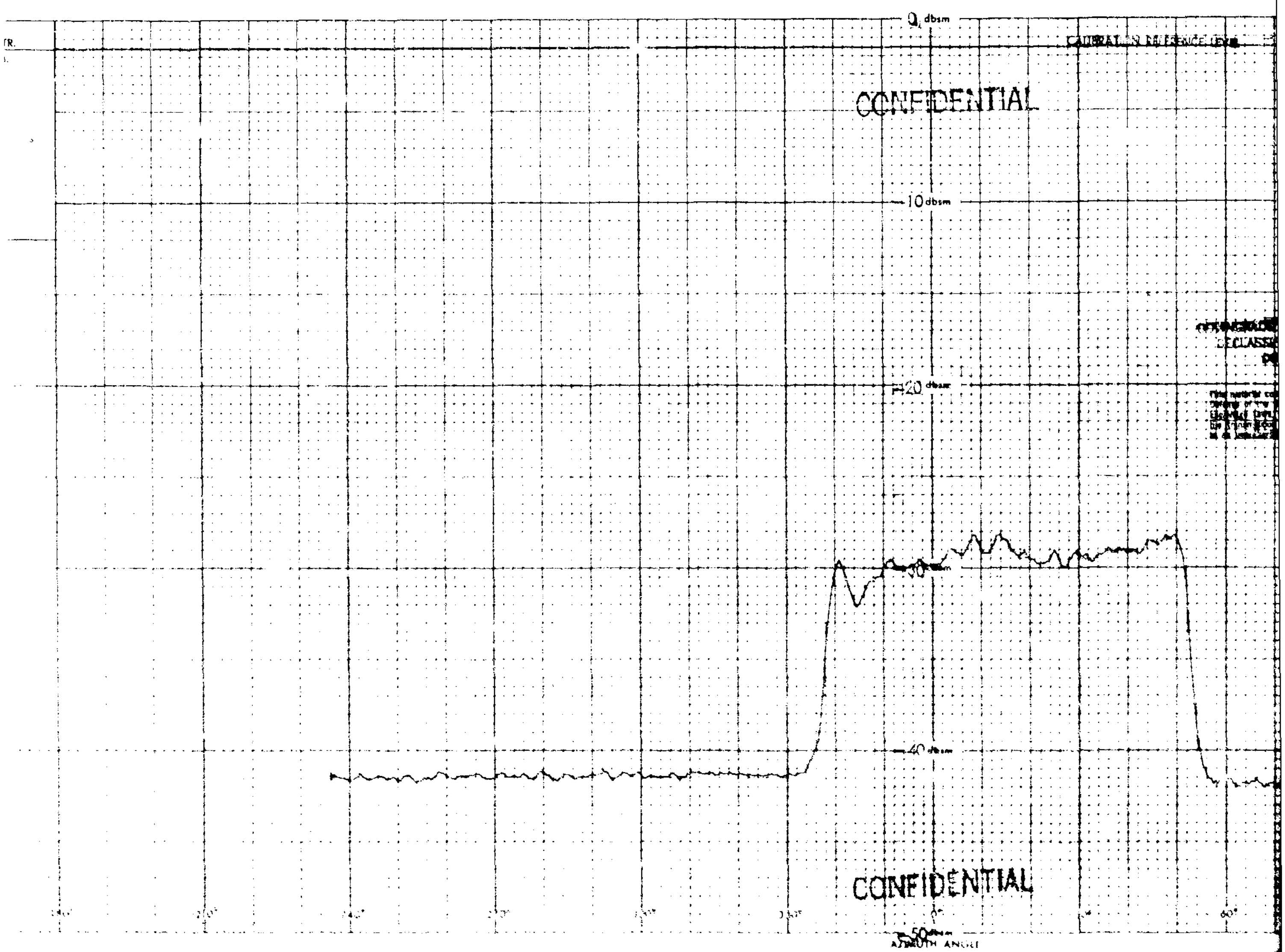
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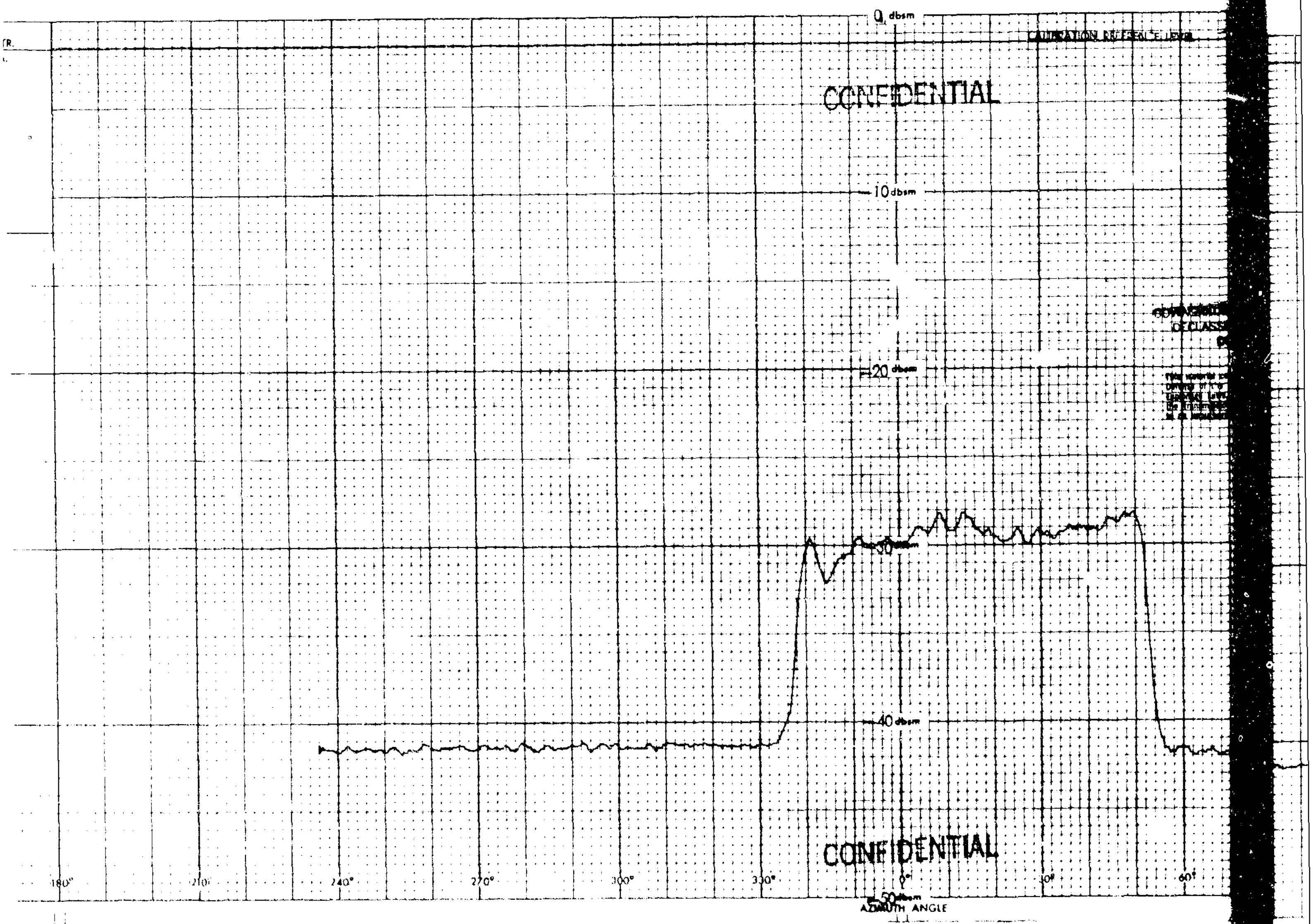

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AZIMUTH ANGLE

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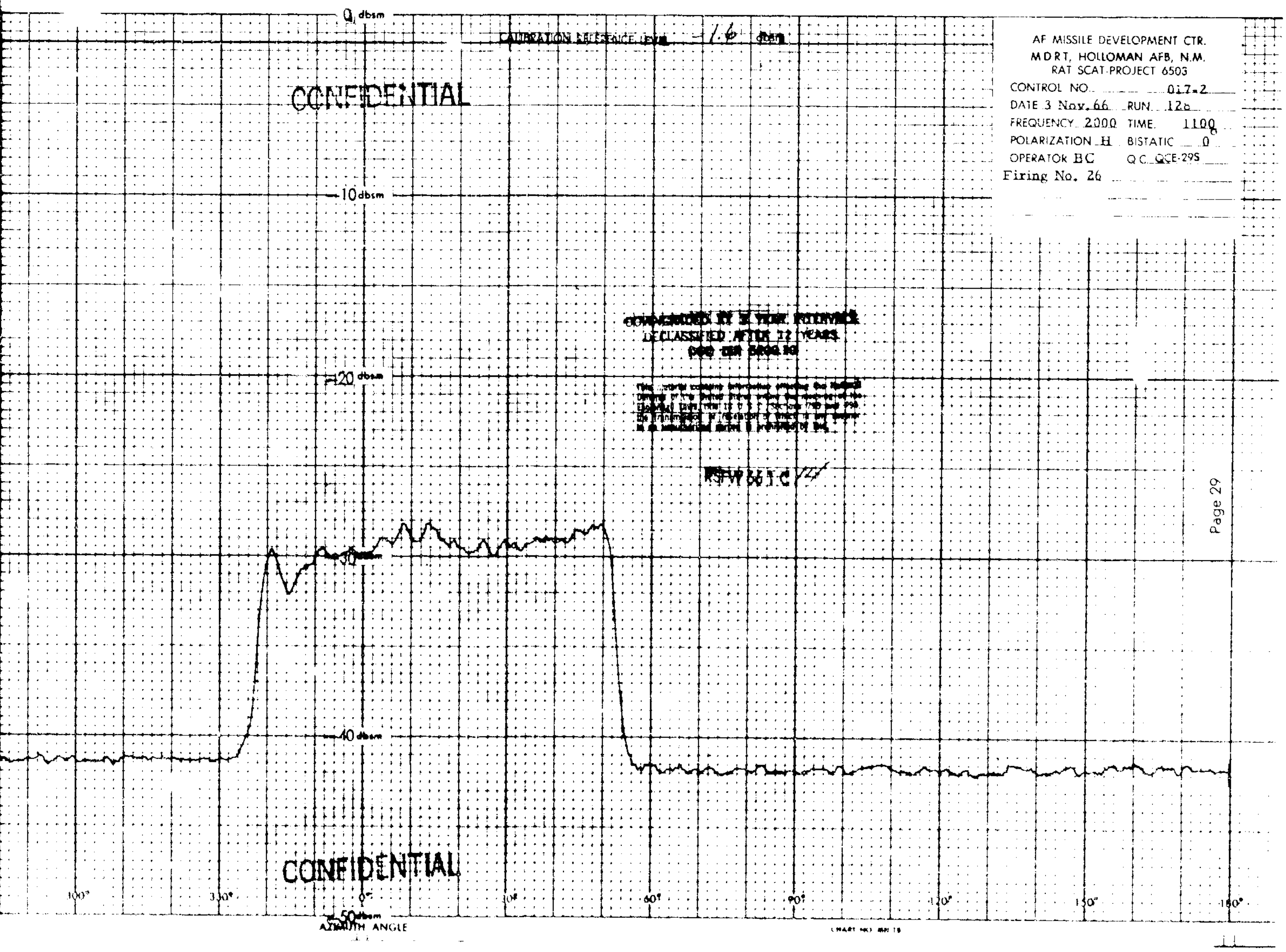
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RAT SCAT-PROJECT 6503
CONTROL NO. 017-2
DATE 3 Nov. 66 RUN 126
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OPERATOR BC Q.C. QCE-29S
Firing No. 26
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DOD DIR 5200.10
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AZIMUTH ANGLE

Page 29

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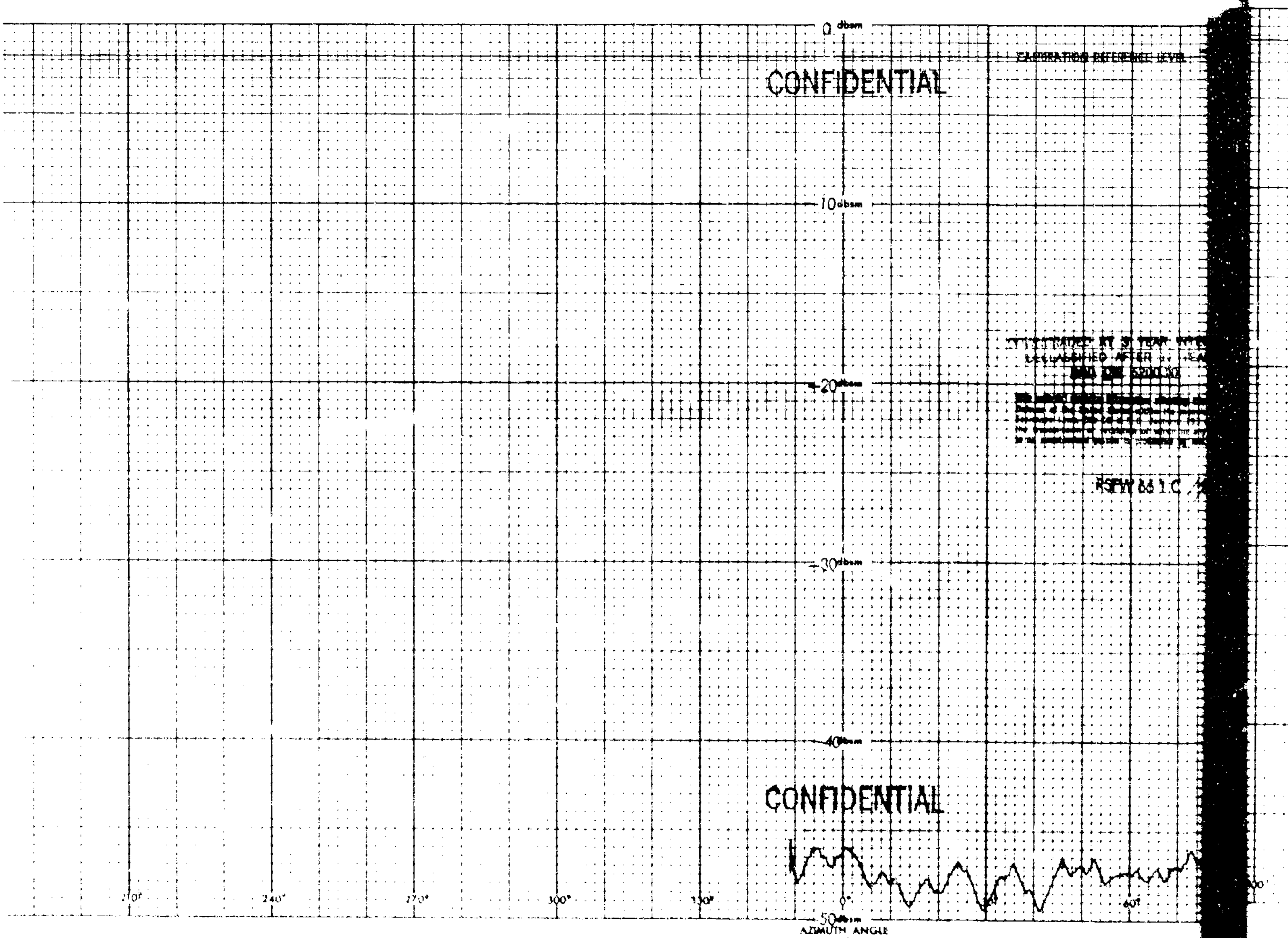
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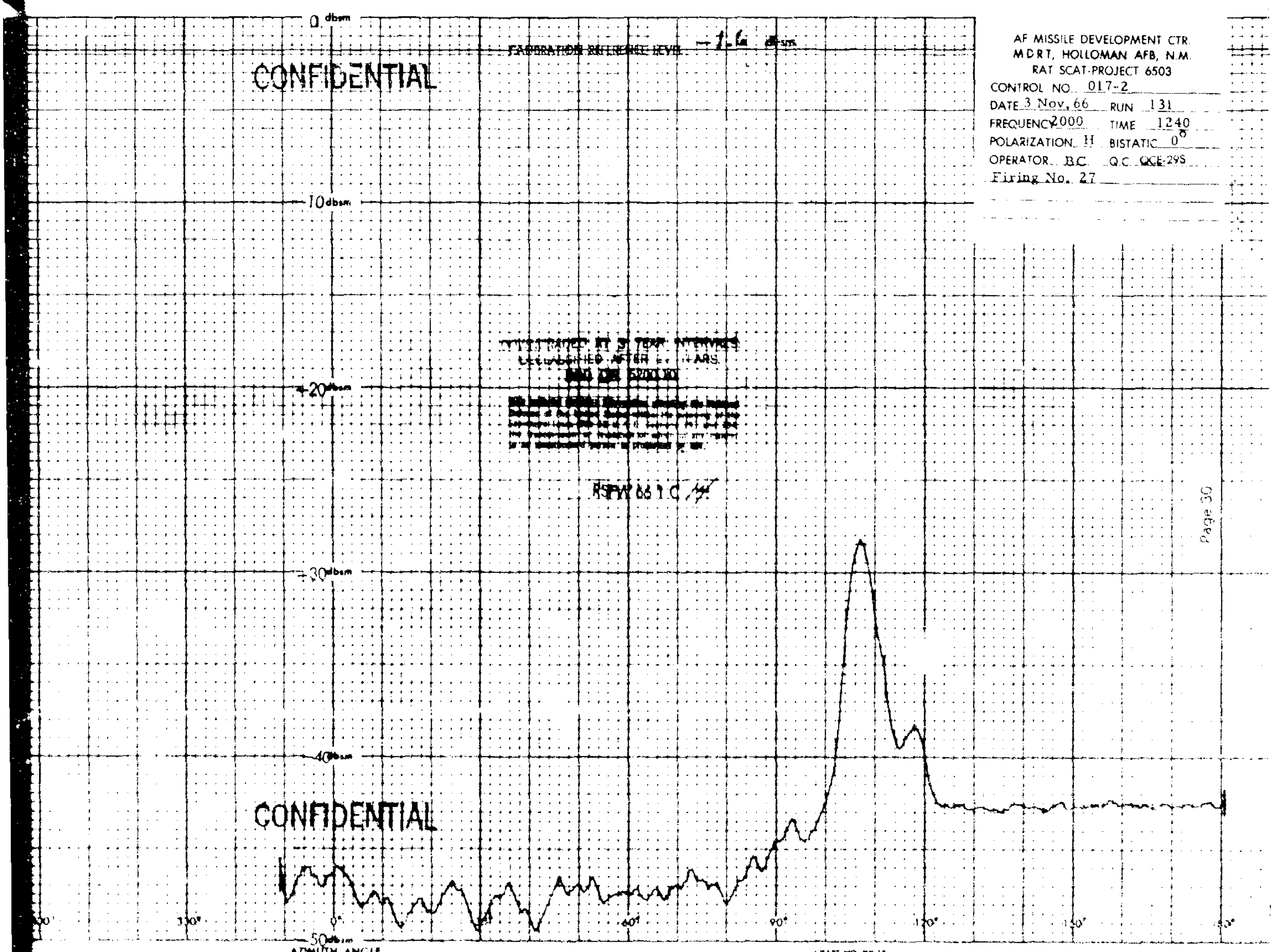
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CONTROL NO. 017-2
DATE 3 Nov. 66 RUN 131
FREQUENCY 2000 TIME 1240
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OPERATOR BC Q.C. QCE-295
Firing No. 27
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Page 30
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AZIMUTH ANGLE

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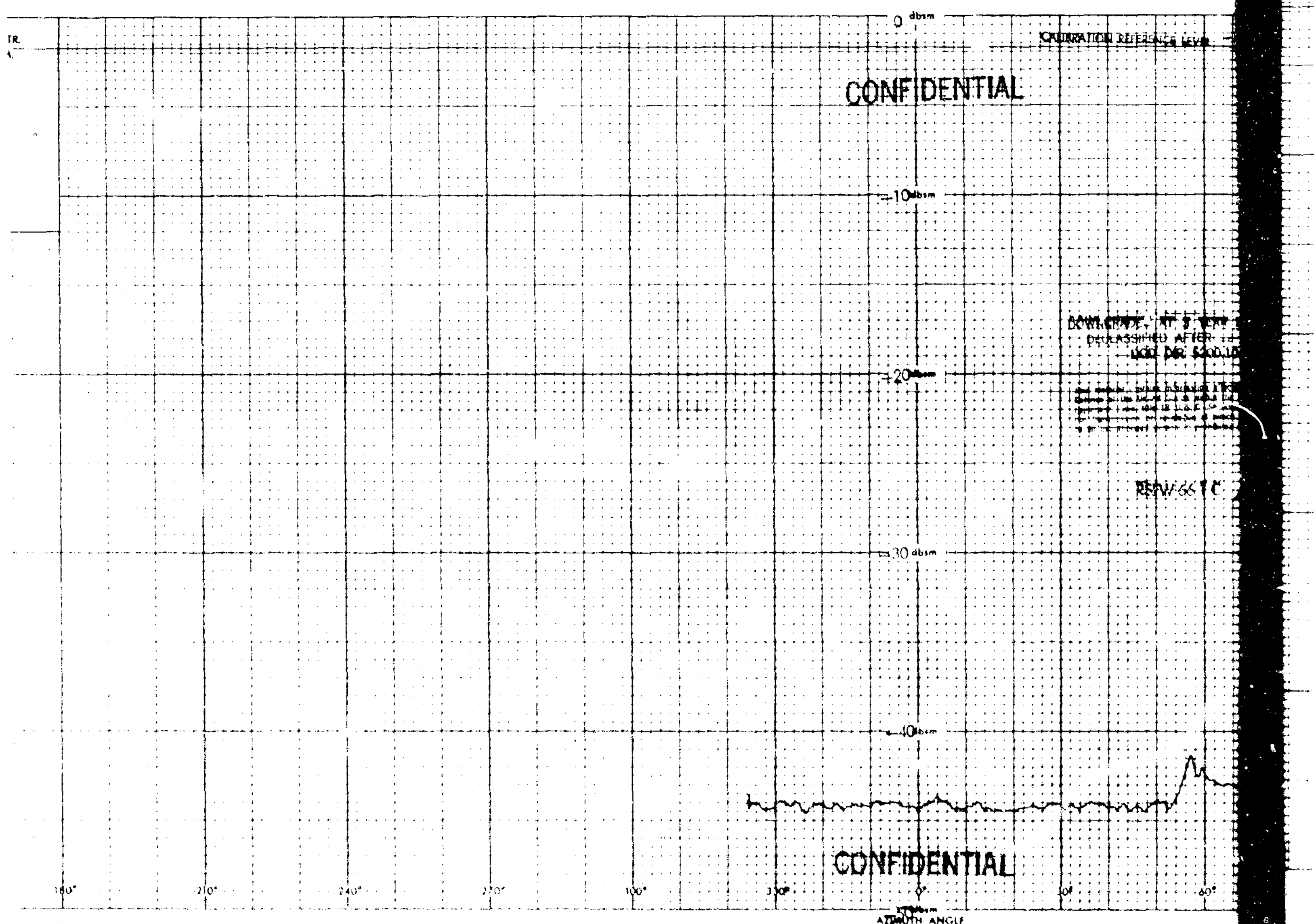
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AZIMUTH ANGLE
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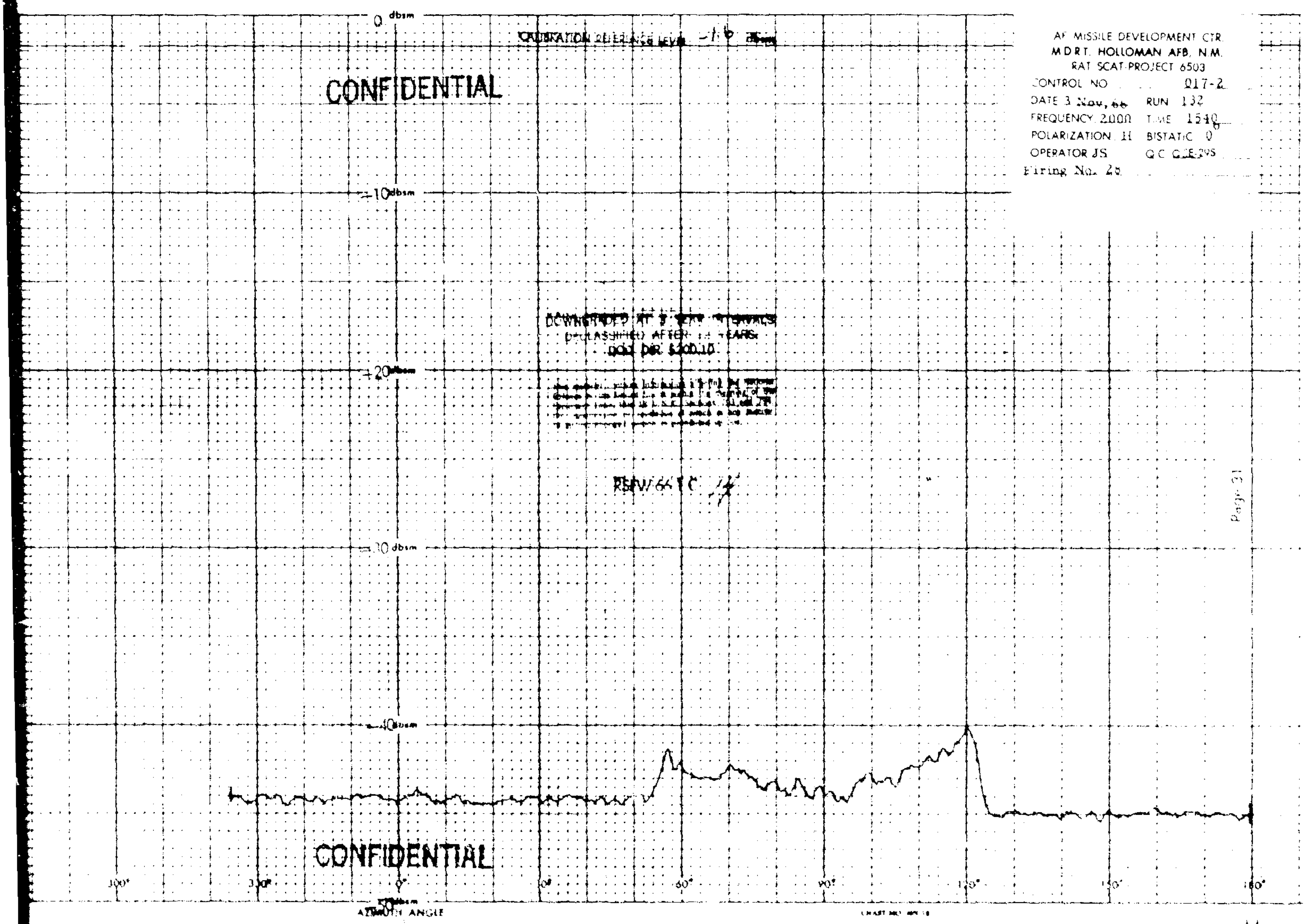
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OPERATOR JS
Firing No. 26
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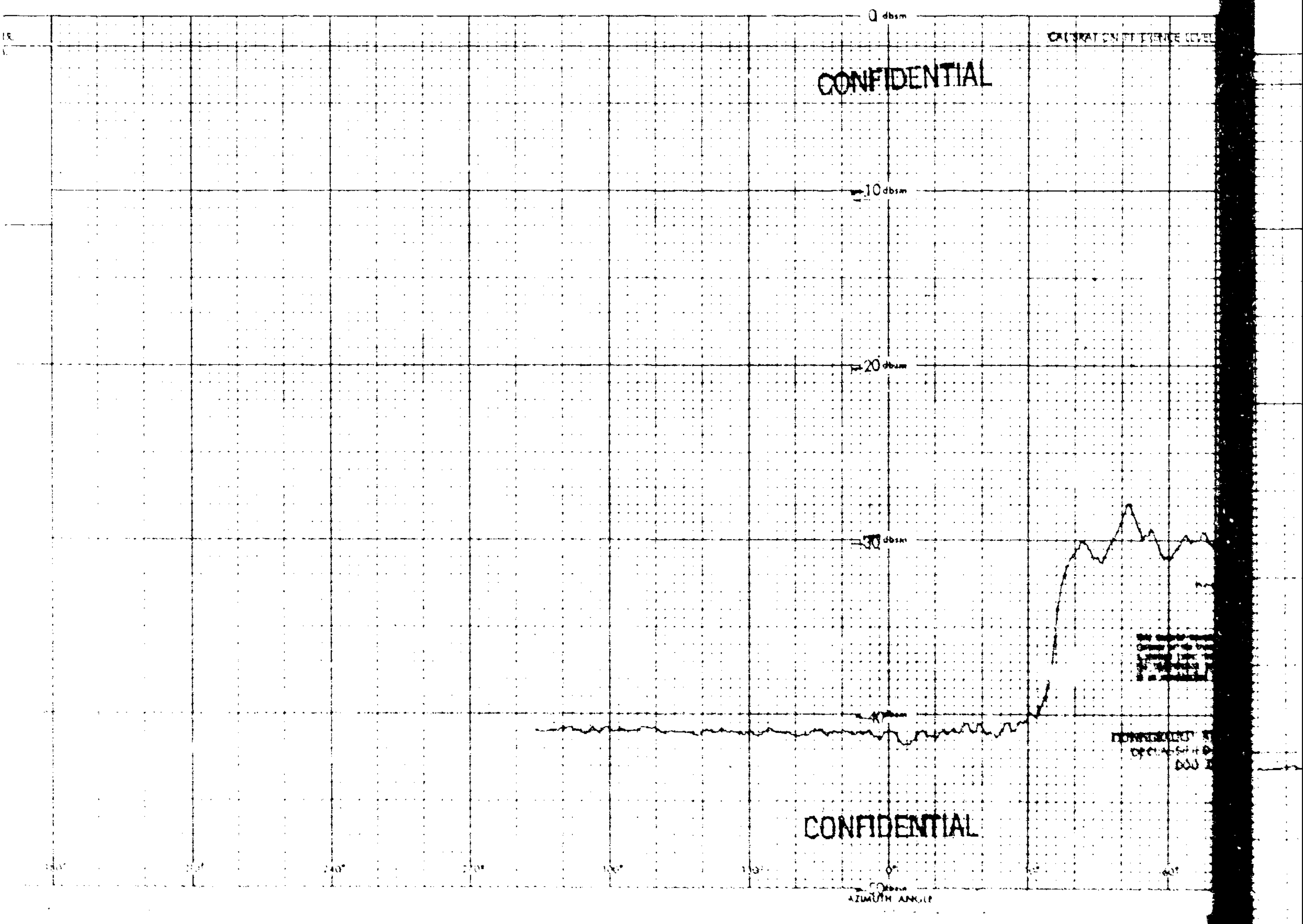
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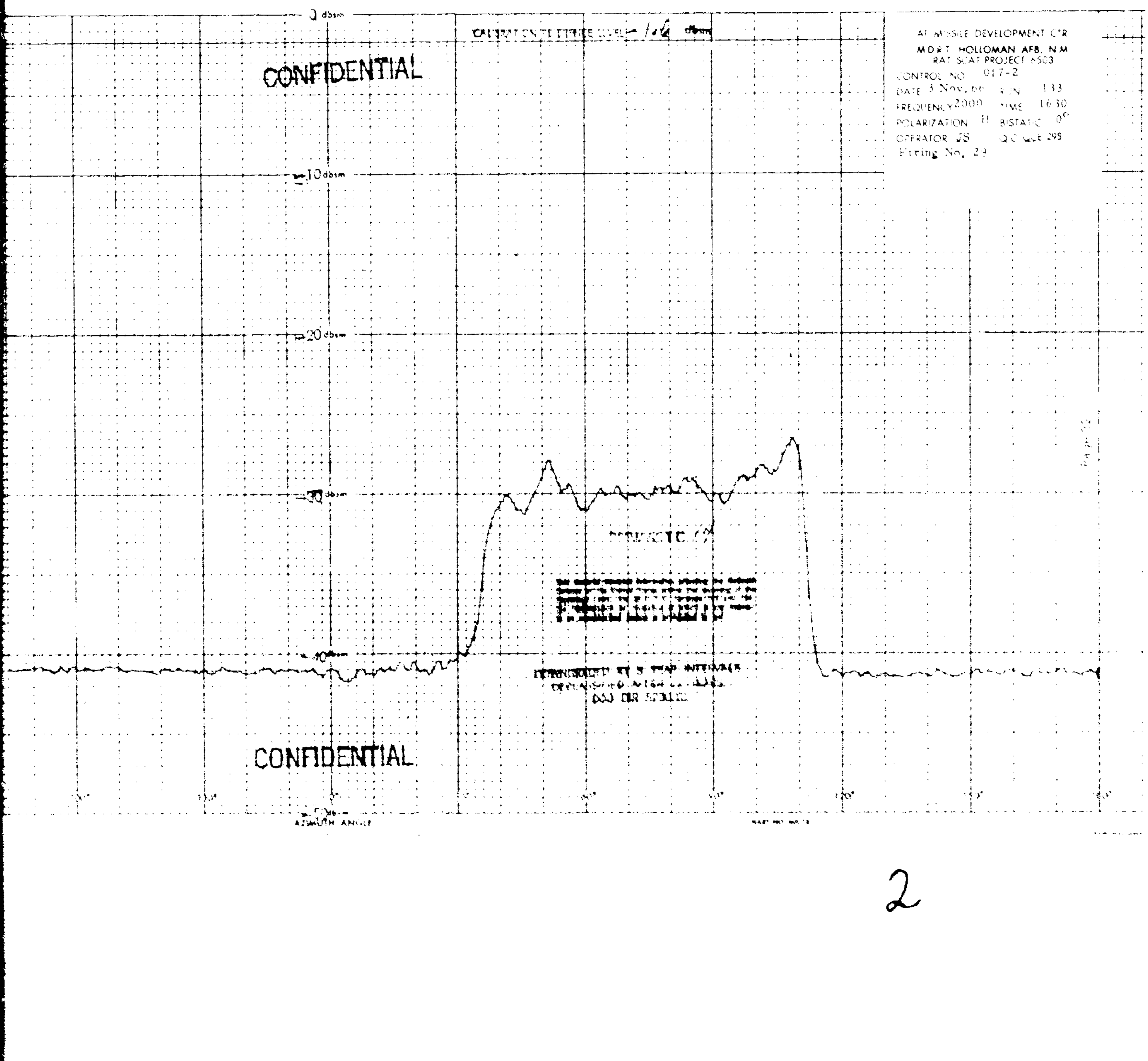
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MDRT HOLLOMAN AFB, N.M.
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CONTROL NO 017-2
DATE 3 Nov. 66 RUN 133
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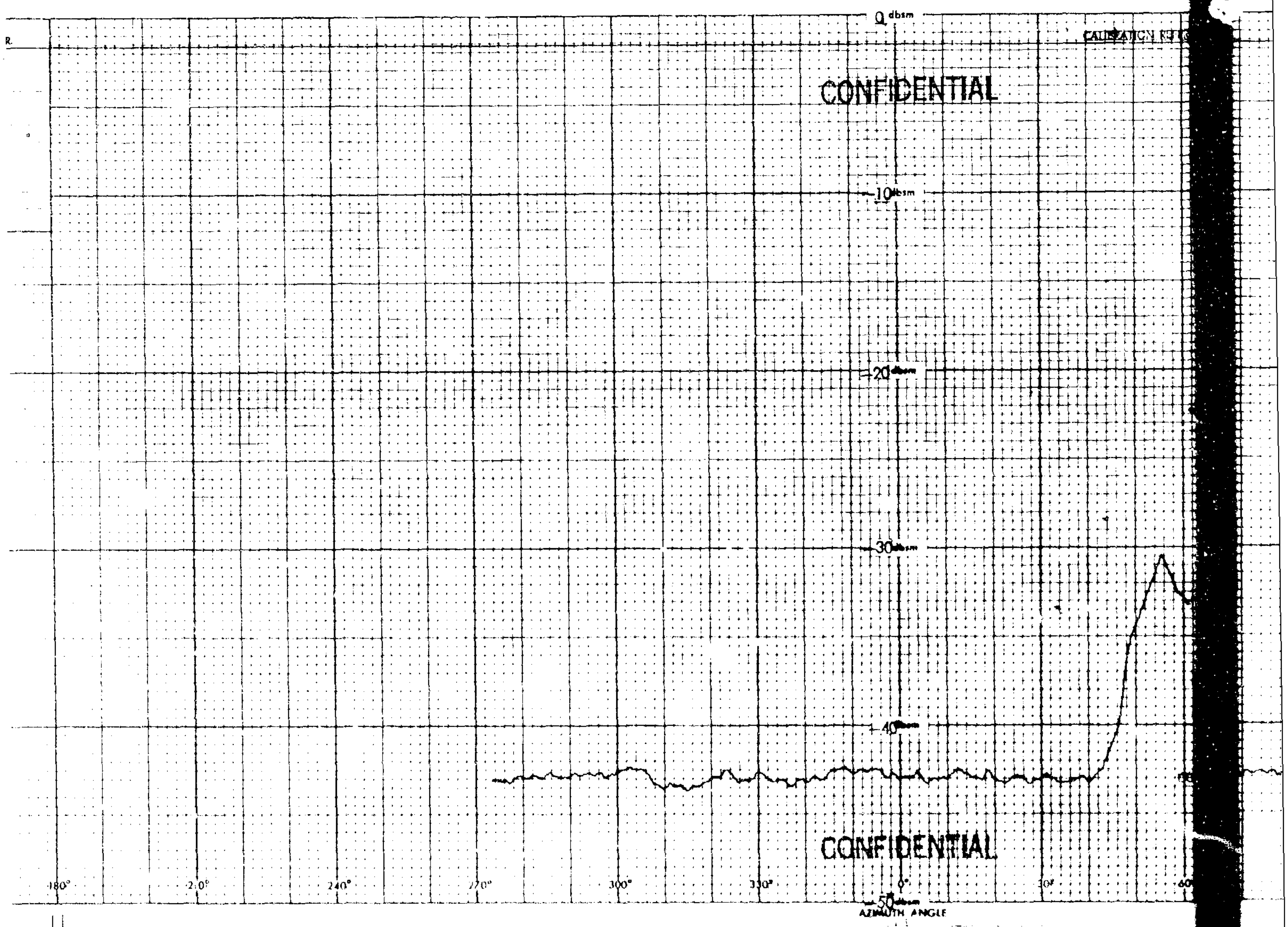
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AZIMUTH ANGLE

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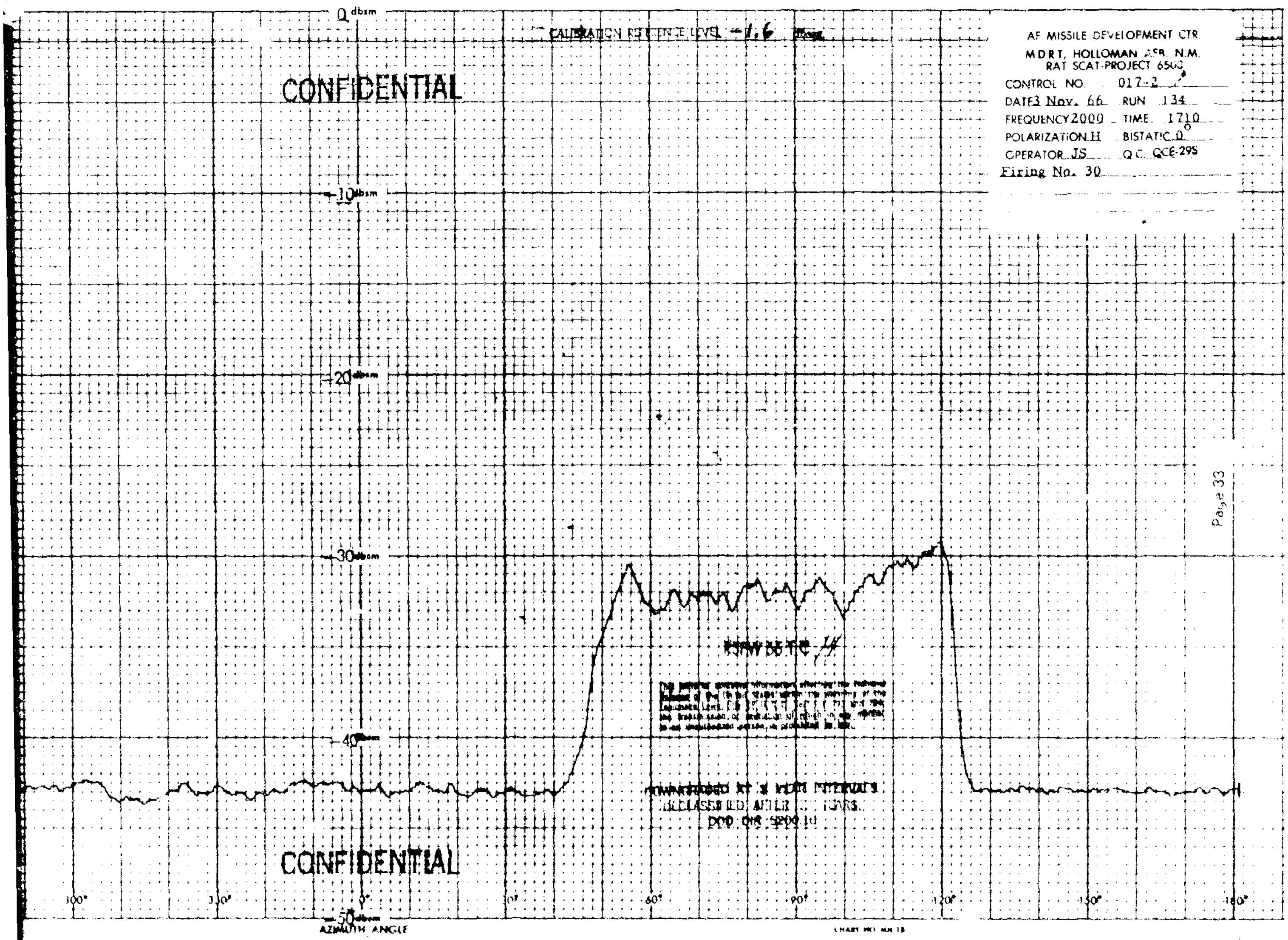
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CONTROL NO. 017-2
DATE 3 Nov. 66 RUN 134
FREQUENCY 2000 TIME 1710
POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-295
Firing No. 30
-10 dbsm
-20 dbsm
-30 dbsm
-40 dbsm
-50 dbsm
Page 33
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CONFIDENTIAL
300°
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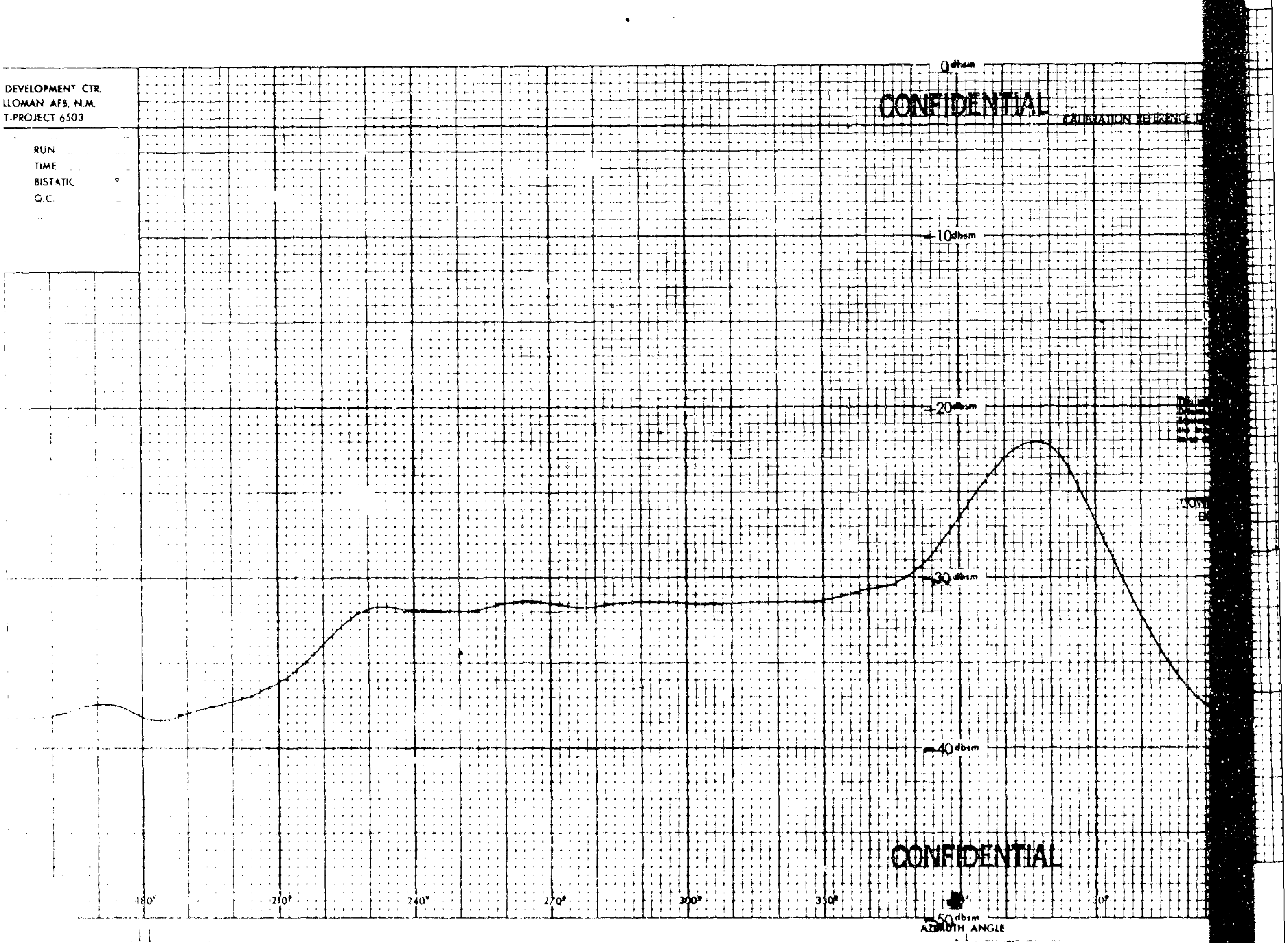
150°
180°
AZIMUTH ANGLE

2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RUN
TIME
BISTATIC
Q.C.
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240°
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AZIMUTH ANGLE

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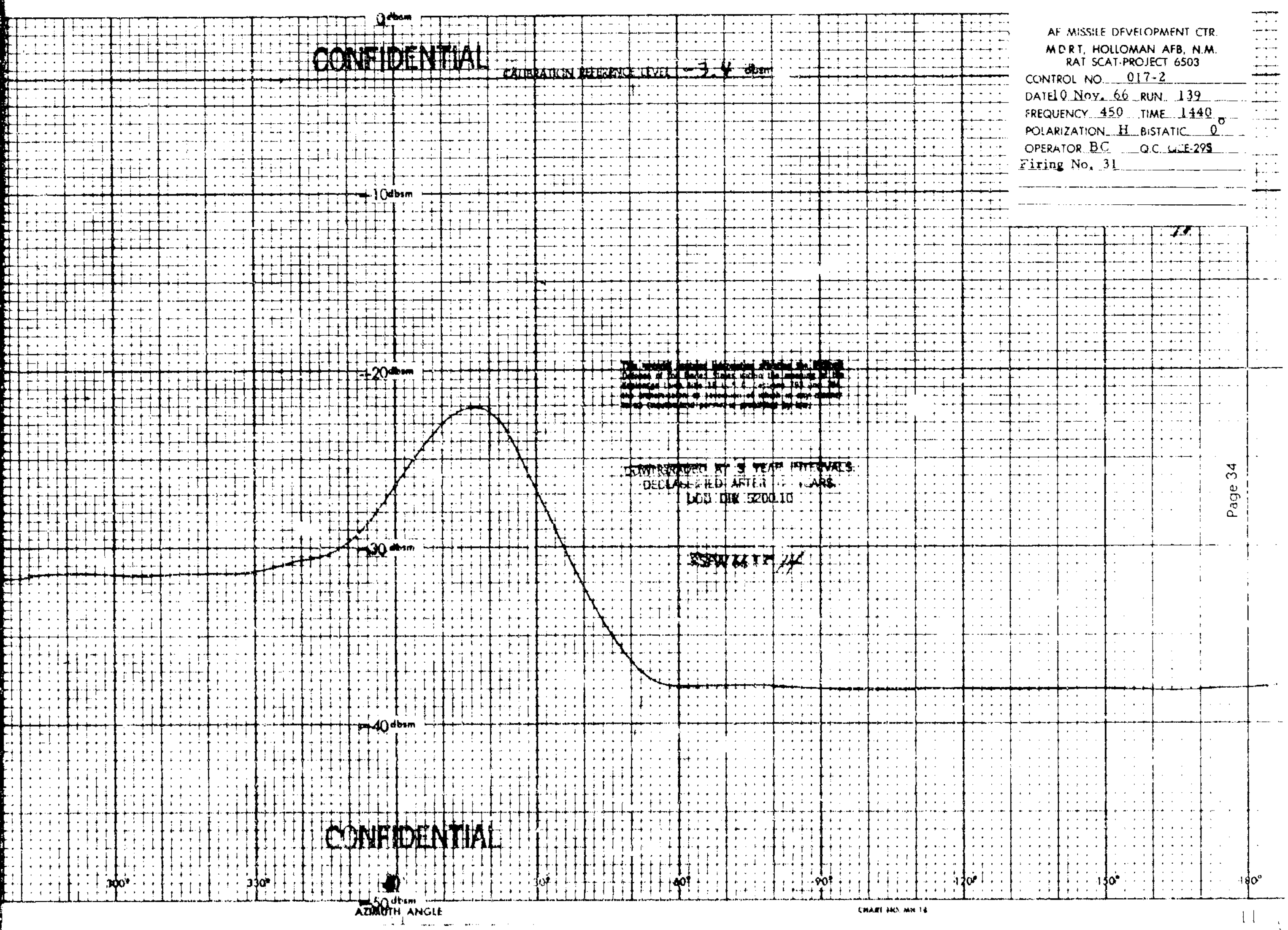
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CONTROL NO. 017-2
DATE 10 Nov. 66 RUN 139
FREQUENCY 450 TIME 1440
POLARIZATION H BISTATIC 0°
OPERATOR BC Q.C.
Firing No. 31
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-50 dbsm
DOWNGRADED AT 3 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS.
DOD DIR 5200.10
CONFIDENTIAL
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90°
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150°
180°
AZIMUTH ANGLE
CHART NO. MN 14

Page 34

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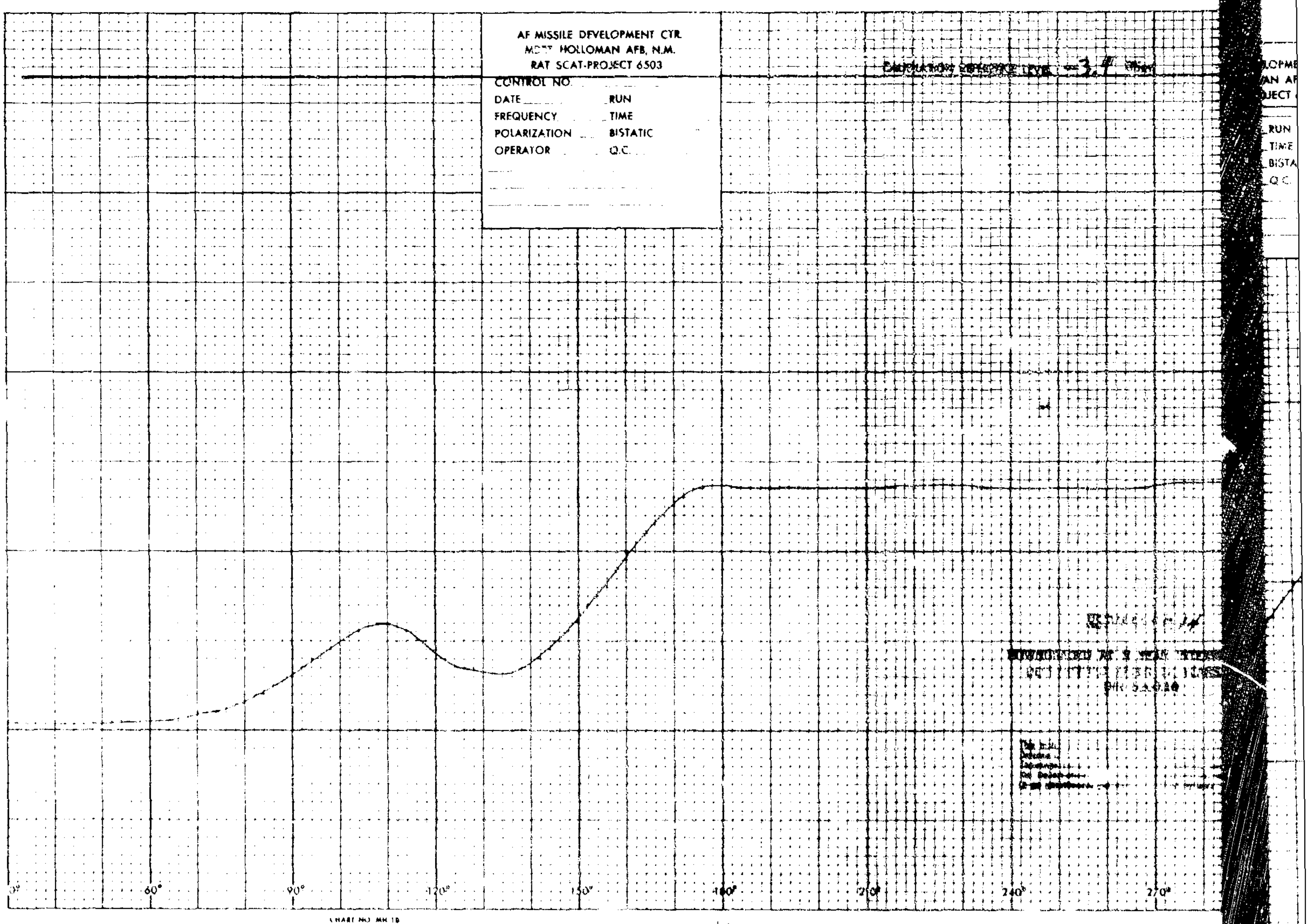
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FREQUENCY
TIME
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OPERATOR
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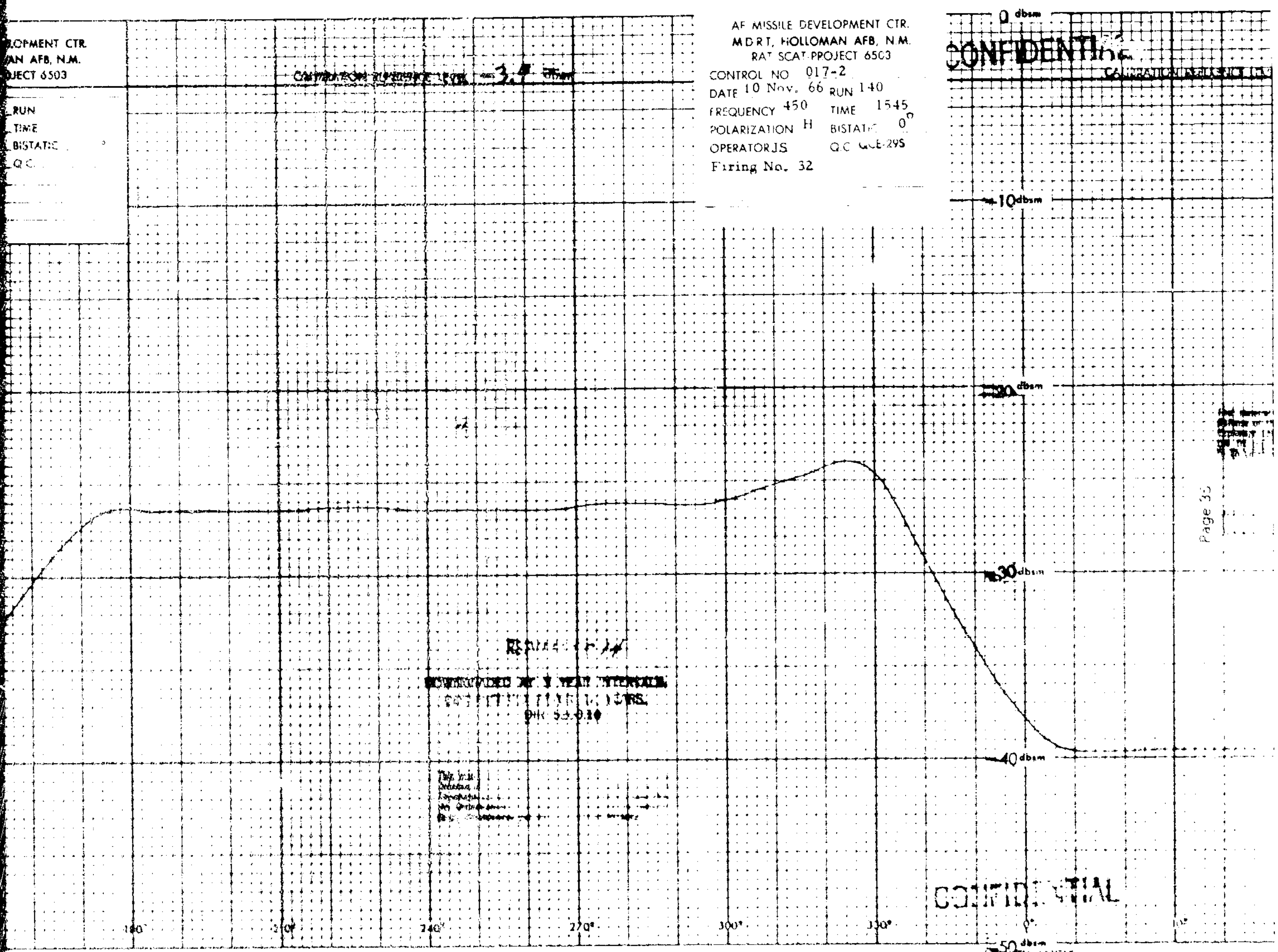
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OPERATOR JS Q.C.
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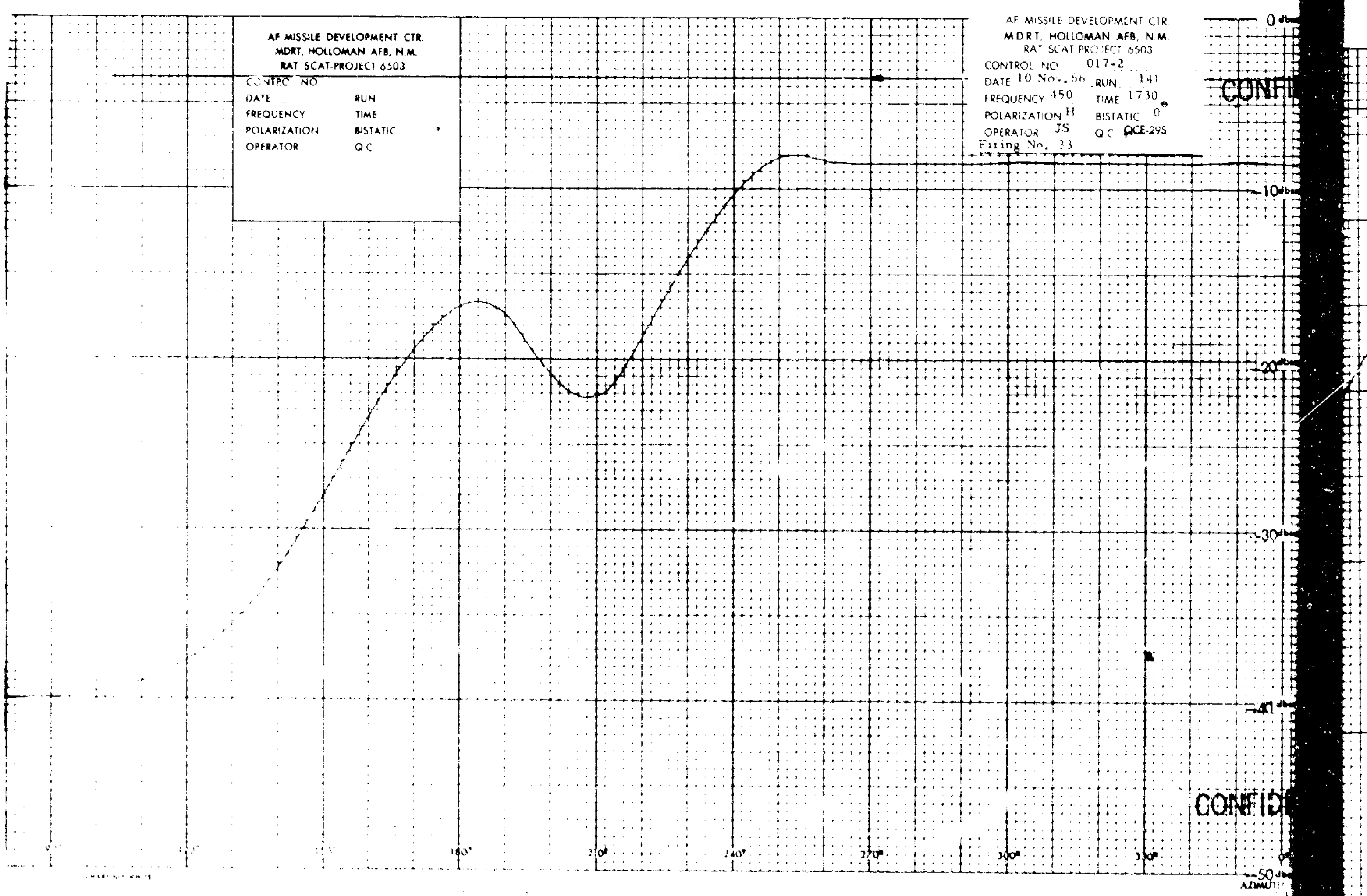
330°
0°
AZIMUTH ANGLE
Page 33
CONFIDENTIAL

2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DATE
RUN
FREQUENCY
TIME
POLARIZATION
BISTATIC
OPERATOR
Q C
AF MISSILE DEVELOPMENT CTR.
MDRT, HOLLOMAN AFB, N.M.
RAT SCAT PROJECT 6503
CONTROL NO 017-2
DATE 10 Nov.56
RUN 141
FREQUENCY 450
TIME 1730
POLARIZATION H
BISTATIC 0°
OPERATOR JS
Q C QCE-295
Firing No. 33
CONF
CONFID
0 dbsm
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AZIMUTH

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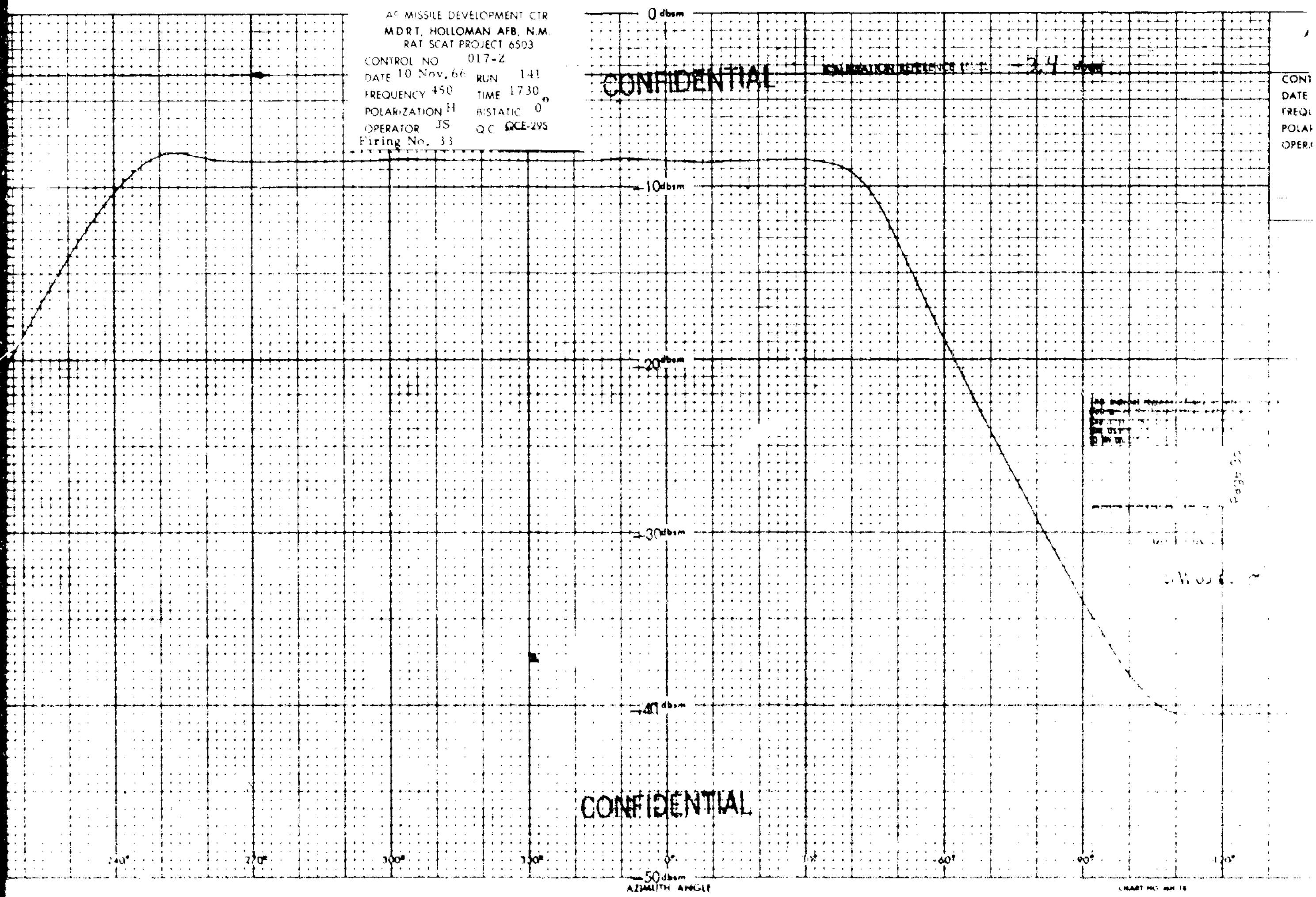
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CONTROL NO 017-2
DATE 10 Nov. 66 RUN 141
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POLARIZATION H BISTATIC 0°
OPERATOR JS Q C QCE-295
Firing No. 33
CONFIDENTIAL
-2.4
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-20 dbsm
-30 dbsm
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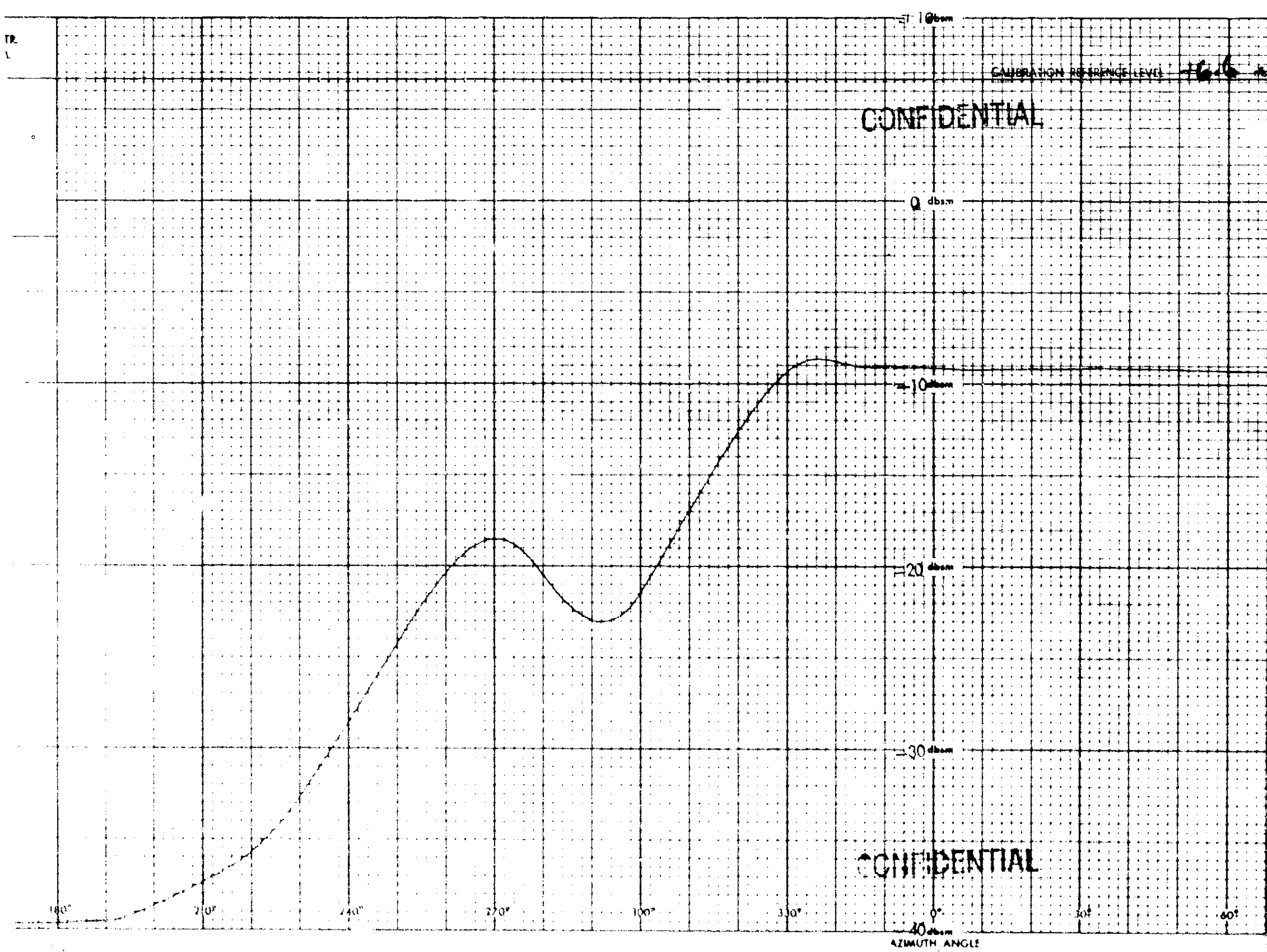

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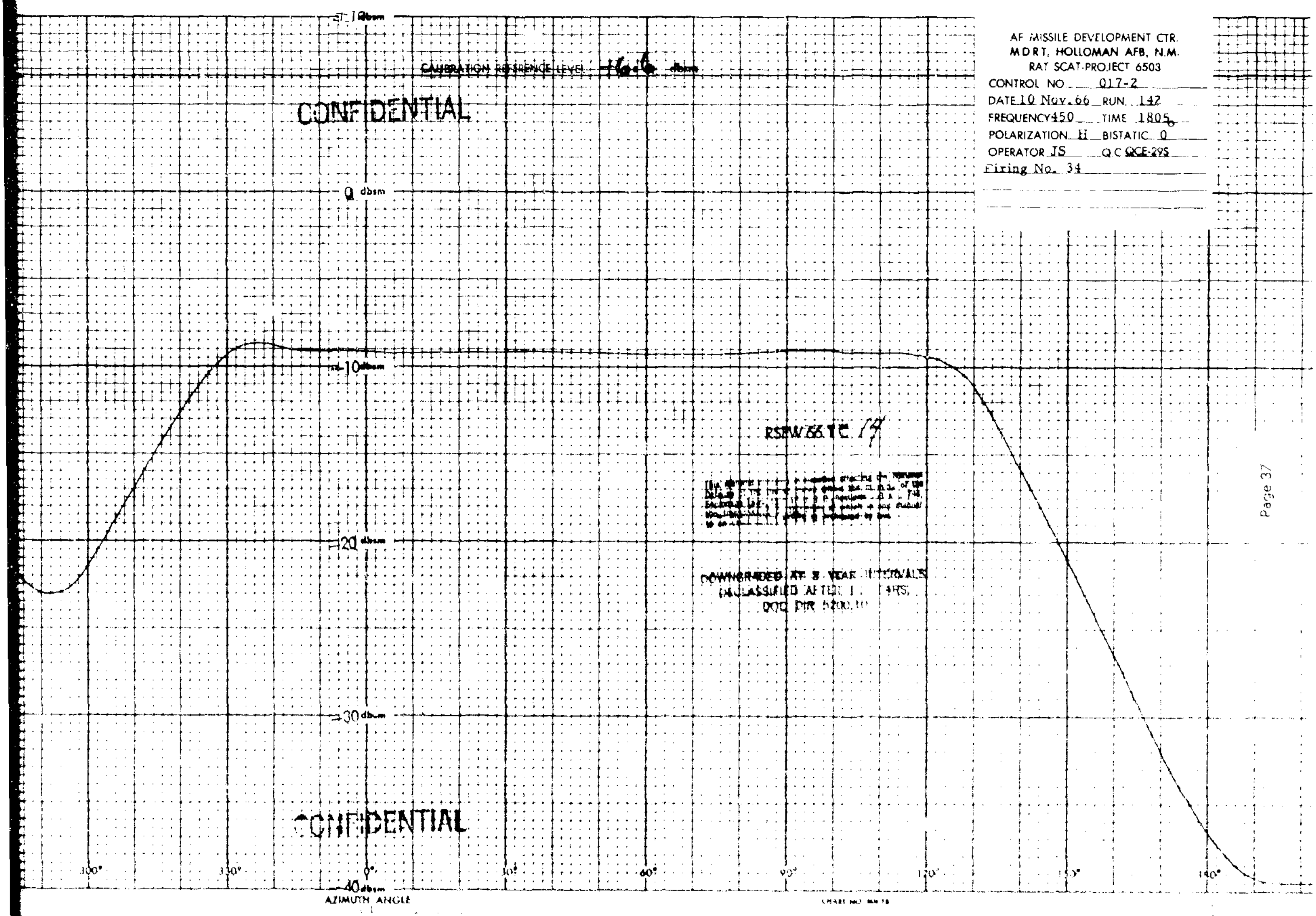

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CONTROL NO. 017-2
DATE 10 Nov. 66 RUN. 142
FREQUENCY 450 TIME 1805
POLARIZATION H BISTATIC 0
OPERATOR JS Q.C QCE-29S
Firing No. 34
+10 dbsm
0 dbsm
-10 dbsm
-20 dbsm
-30 dbsm
-40 dbsm
RSEW 66 TC 19
DOWNGRADED AT 3 YEAR INTERVALS
DECLASSIFIED AFTER 12 YEARS.
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AZIMUTH ANGLE

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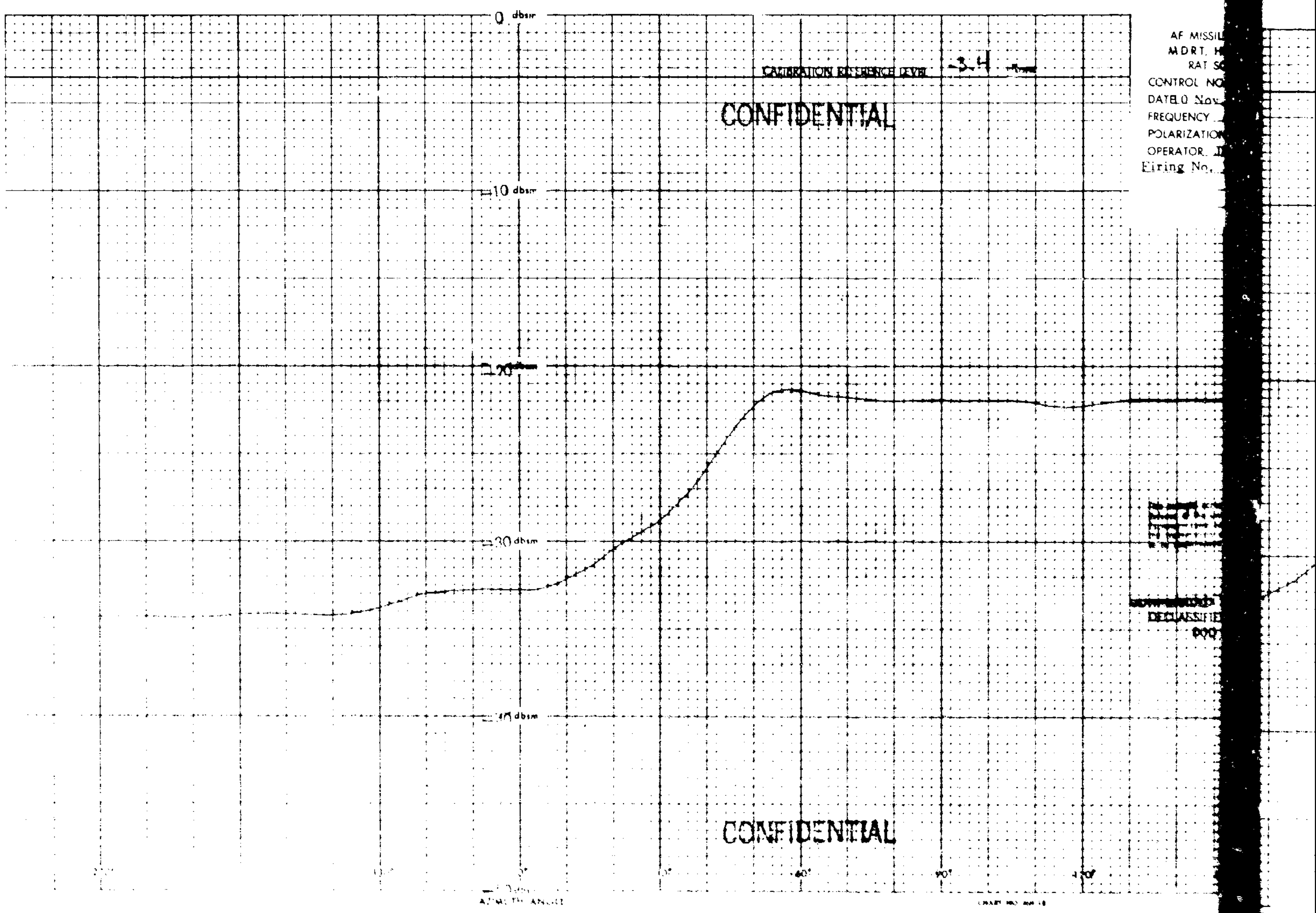
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MDRT, H
RAT S
CONTROL NO
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OPERATOR
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AZIMUTH ANGLE
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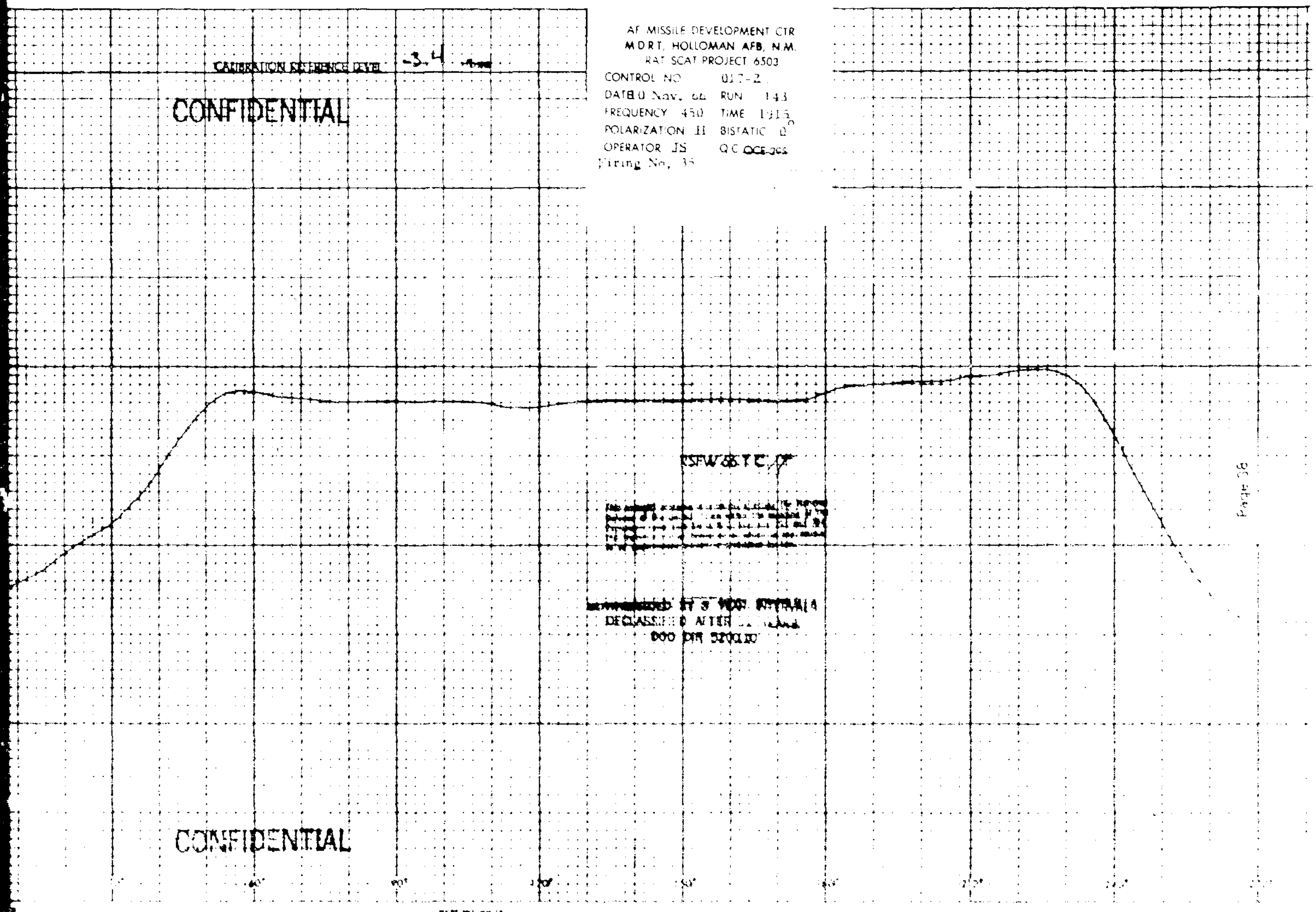
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DATE
RUN 143
FREQUENCY 450
TIME
POLARIZATION H
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OPERATOR JS
Firing No. 35
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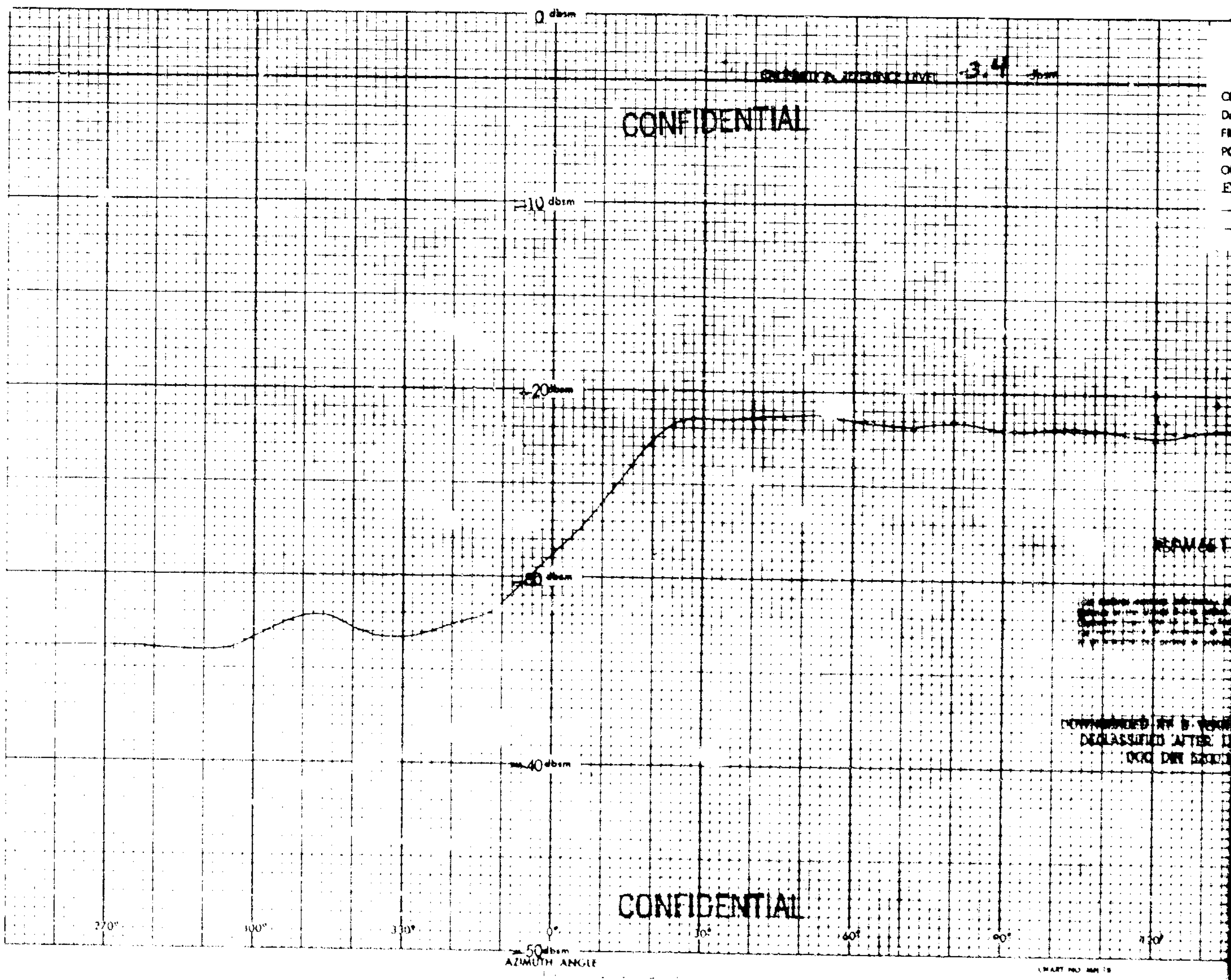

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AZIMUTH ANGLE
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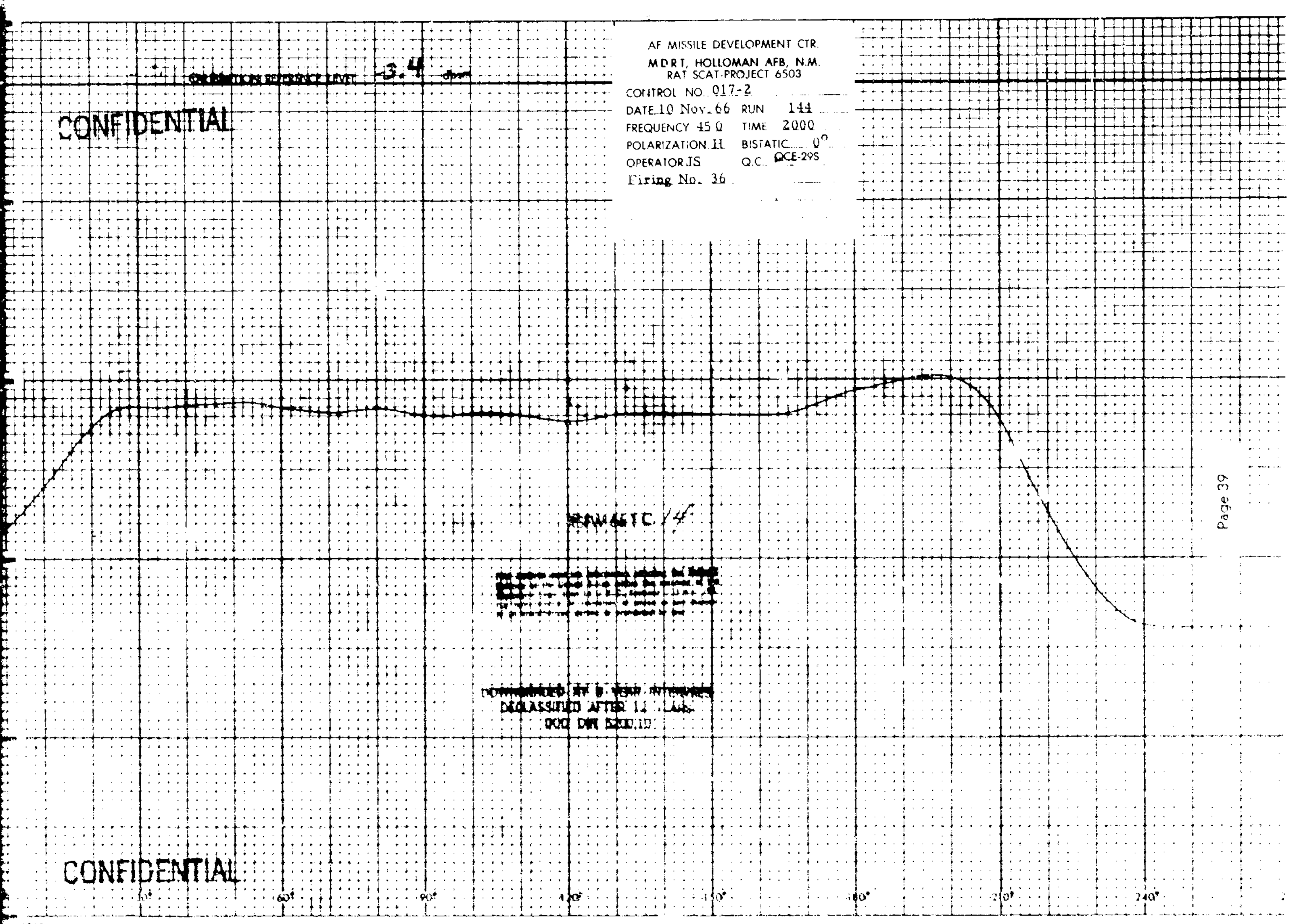
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DATE 10 Nov. 66 RUN 144
FREQUENCY 45 0 TIME 2000
POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-29S
Firing No. 36
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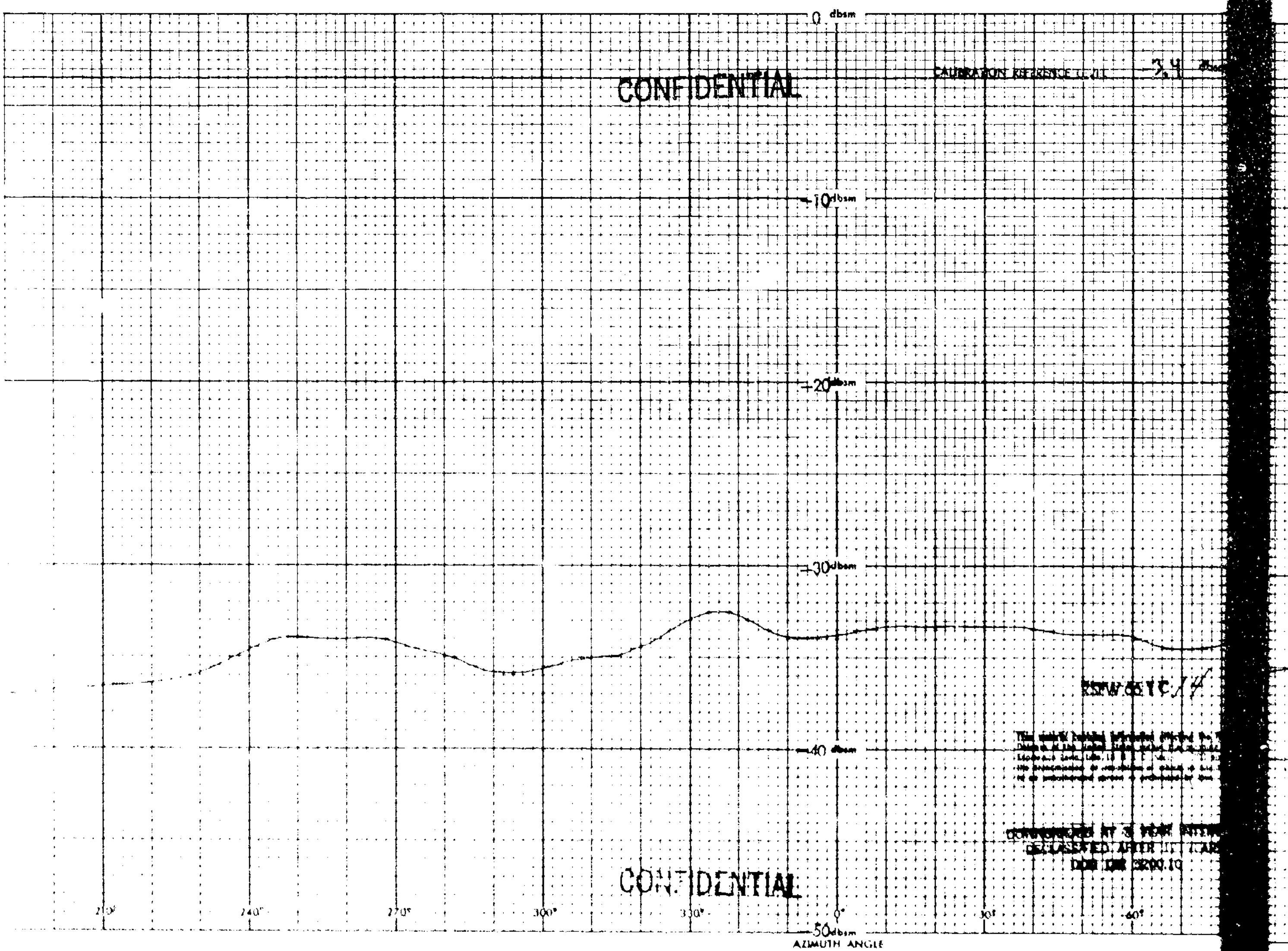
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RSFW 65 T C 14
DECLASSIFIED AFTER
DOD DIR 5200.10
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AZIMUTH ANGLE

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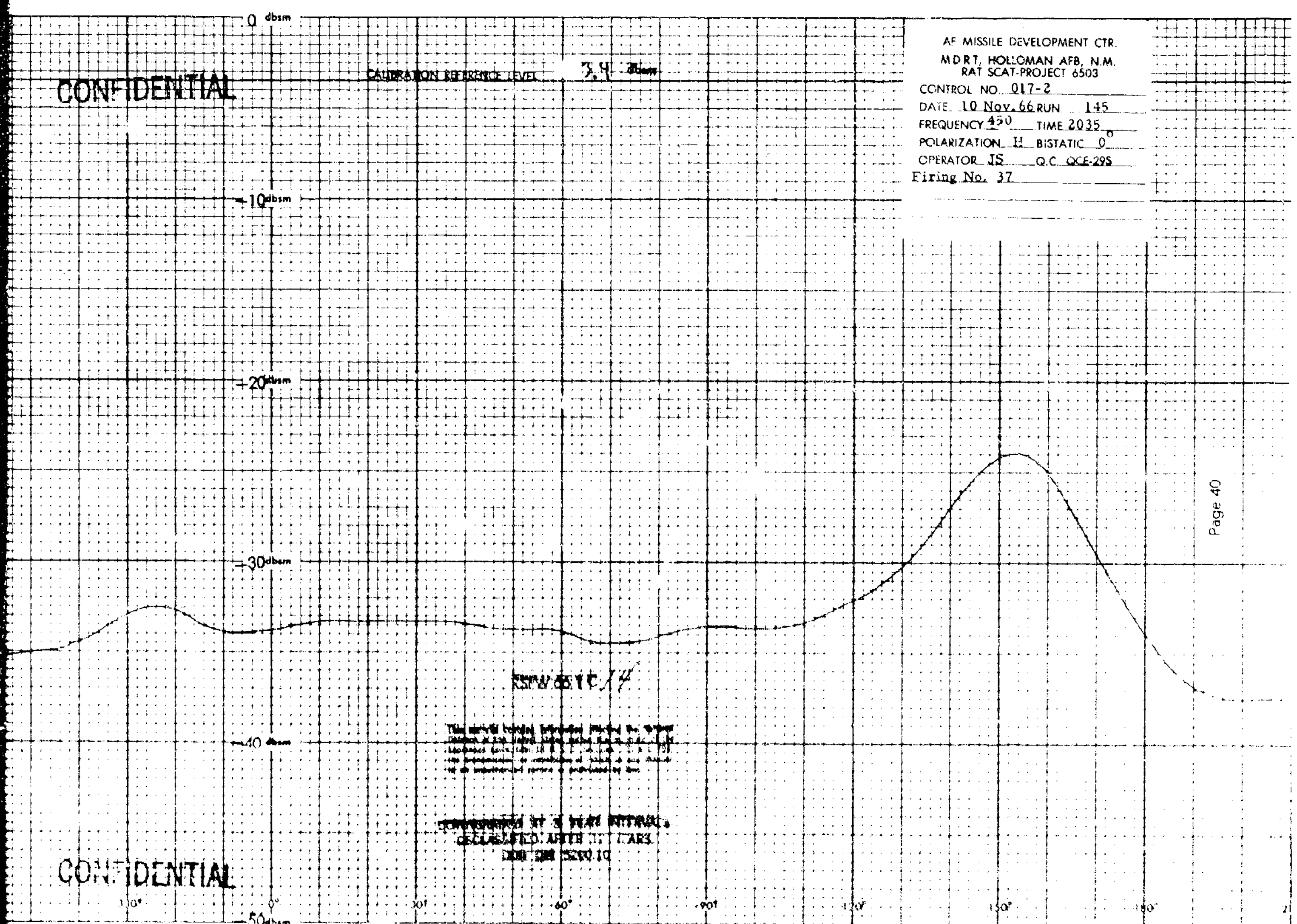

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CONTROL NO. 017-2
DATE 10 Nov. 66 RUN 145
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POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-29S
Firing No. 37
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-30 dbsm
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Page 40
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AZIMUTH ANGLE

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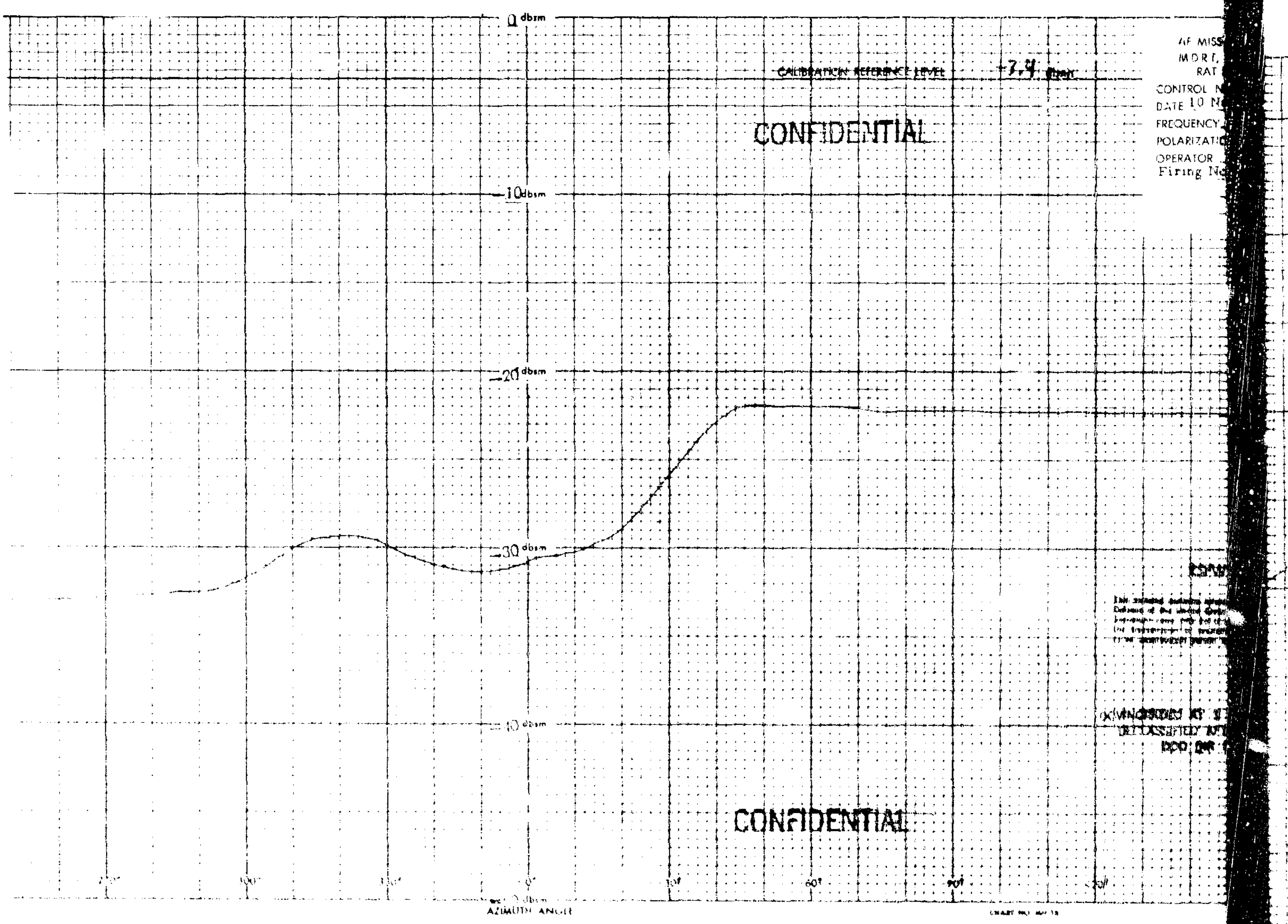
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CONTROL
DATE 10
FREQUENCY
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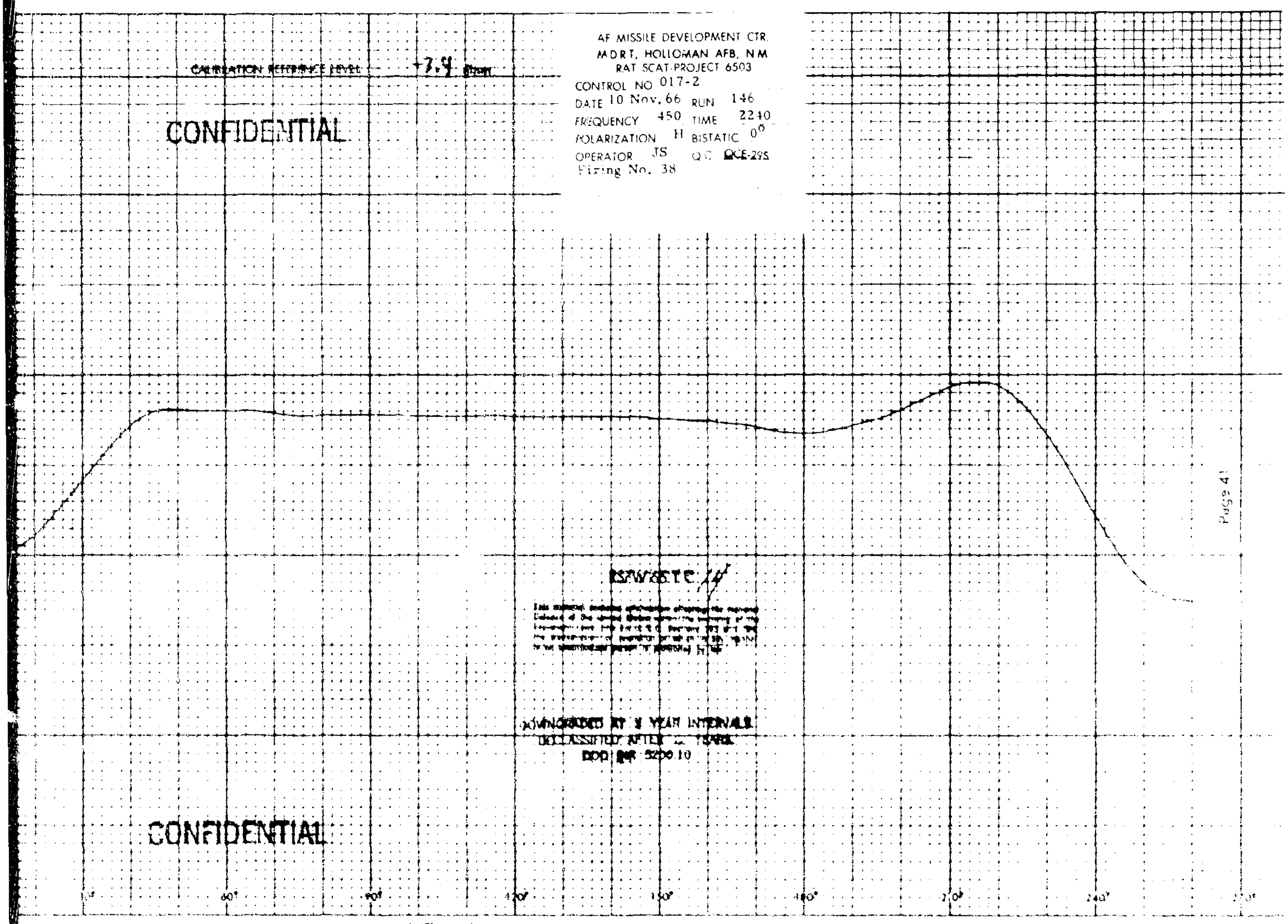
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CONTROL NO 017-2
DATE 10 Nov, 66 RUN 146
FREQUENCY 450 TIME 2240
POLARIZATION H BISTATIC 0°
OPERATOR JS
Firing No. 38
CONFIDENTIAL
Page 41
DOWNGRADED AT 3 YEAR INTERVALS
DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10
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60°
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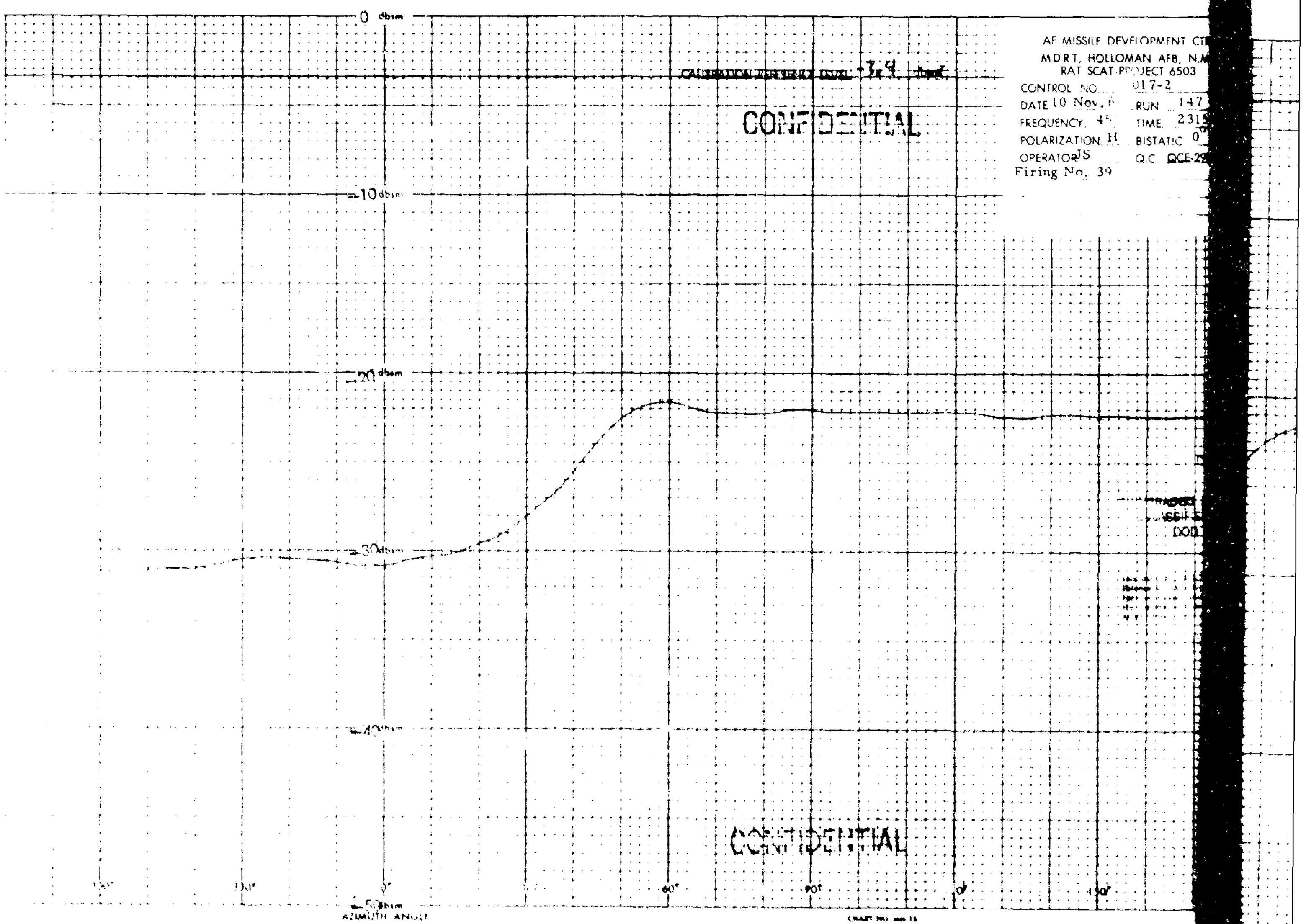

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-20 dbsm
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AZIMUTH ANGLE
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60°
90°
AF MISSILE DEVELOPMENT CT
MDRT, HOLLOMAN AFB, N.M
RAT SCAT-PROJECT 6503
CONTROL NO. 017-2
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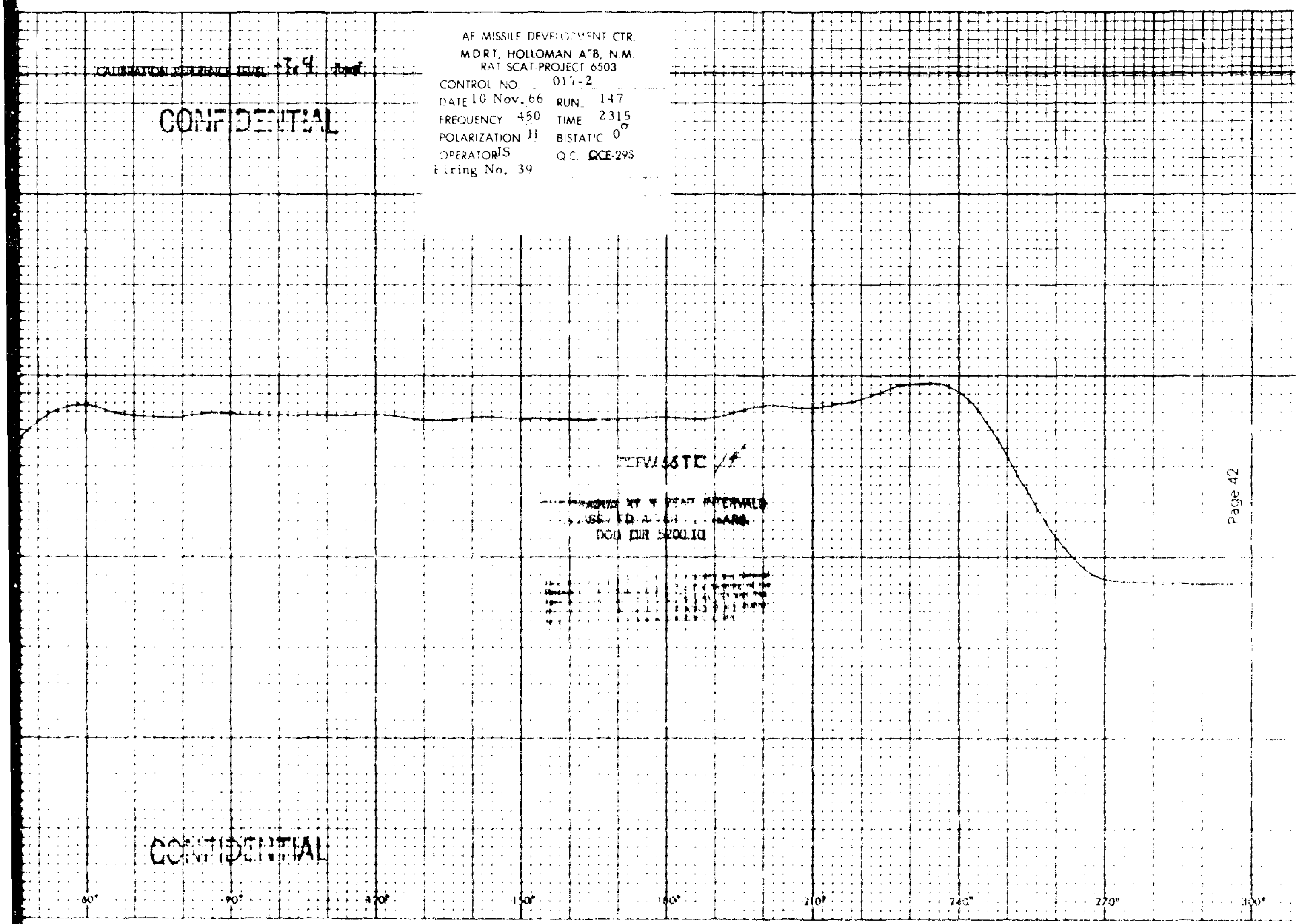
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BISTATIC 0°
OPERATOR JS
Q.C. QCE-295
ring No. 39
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300°

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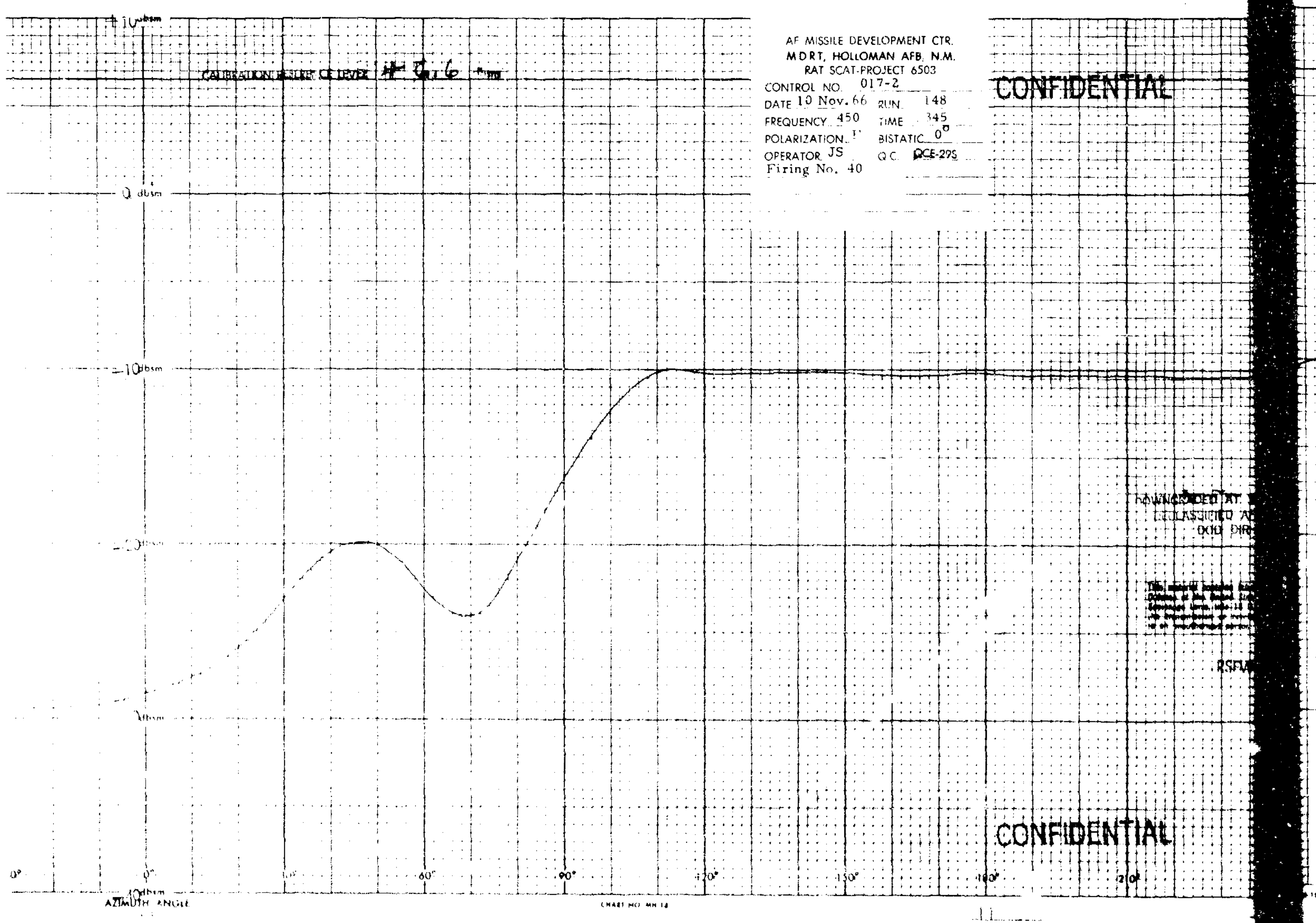
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BISTATIC 0°
OPERATOR JS
Q.C. QCE-295
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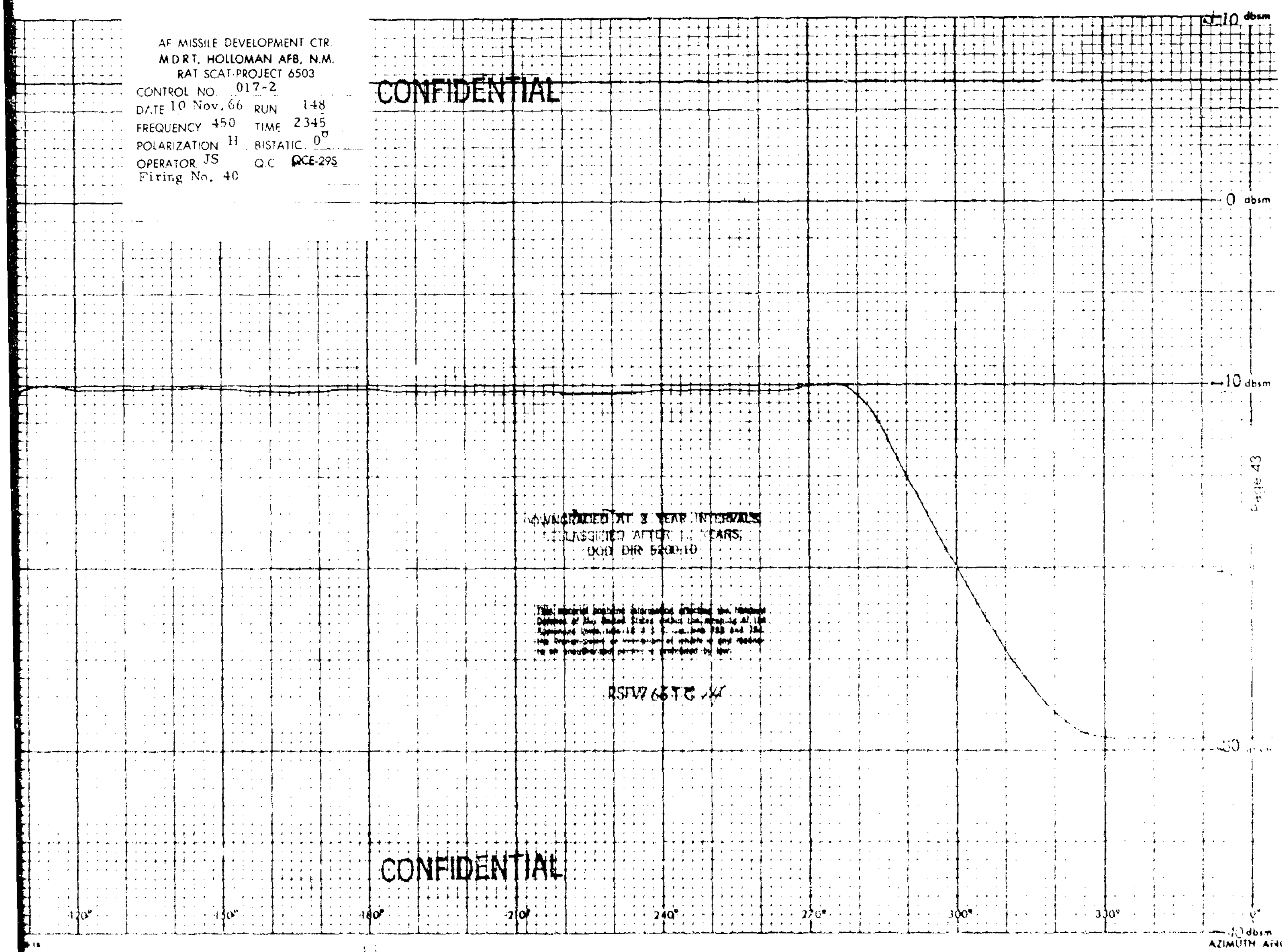
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OPERATOR JS Q.C QCE-295
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0 dbsm
-10 dbsm
-20
DOWNGRADED AT 3 YEAR INTERVALS
DOD DIR 5200.10
RSFV7 66 TG
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AZIMUTH ANG

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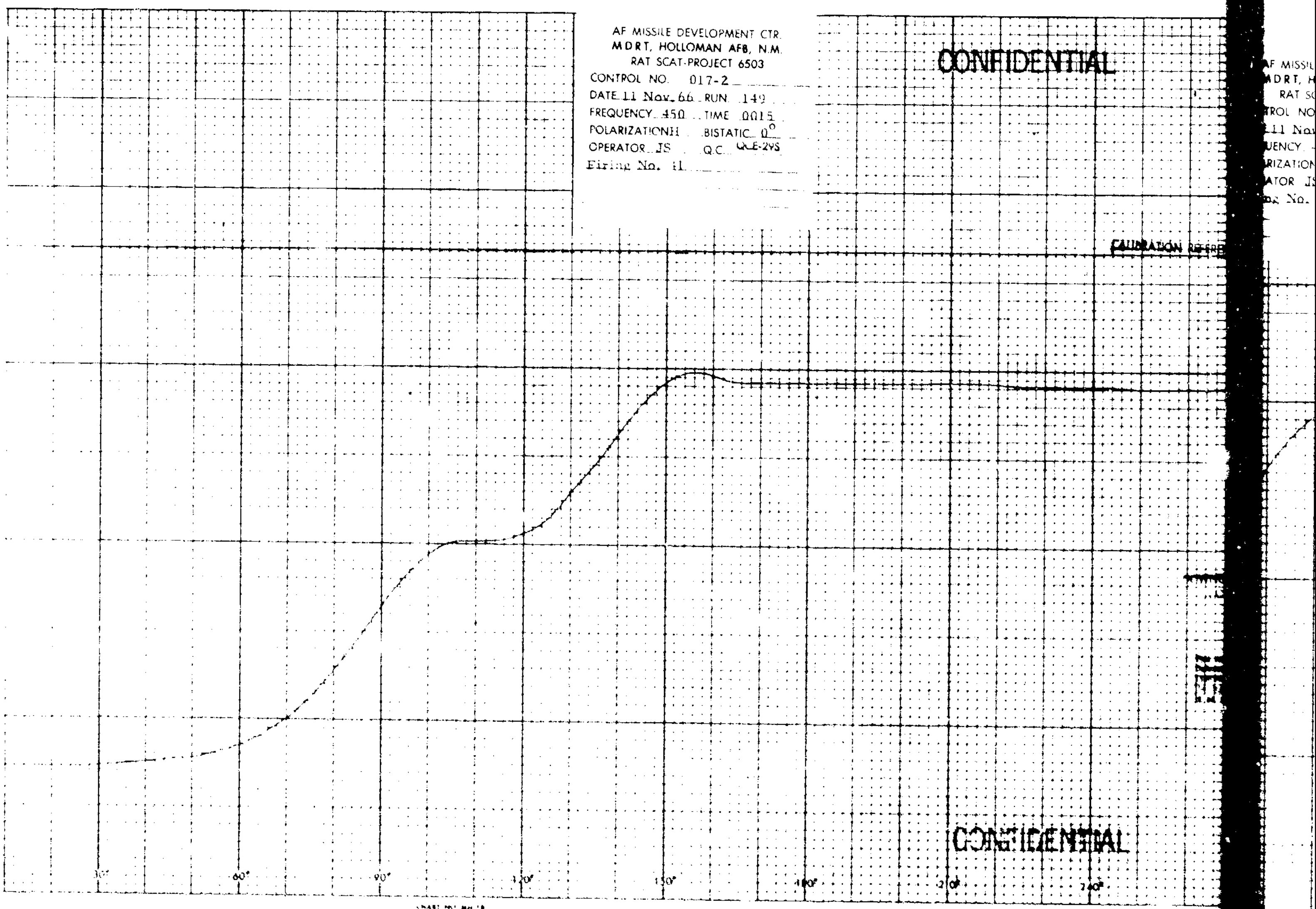
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FREQUENCY 450 TIME 0015
POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C.
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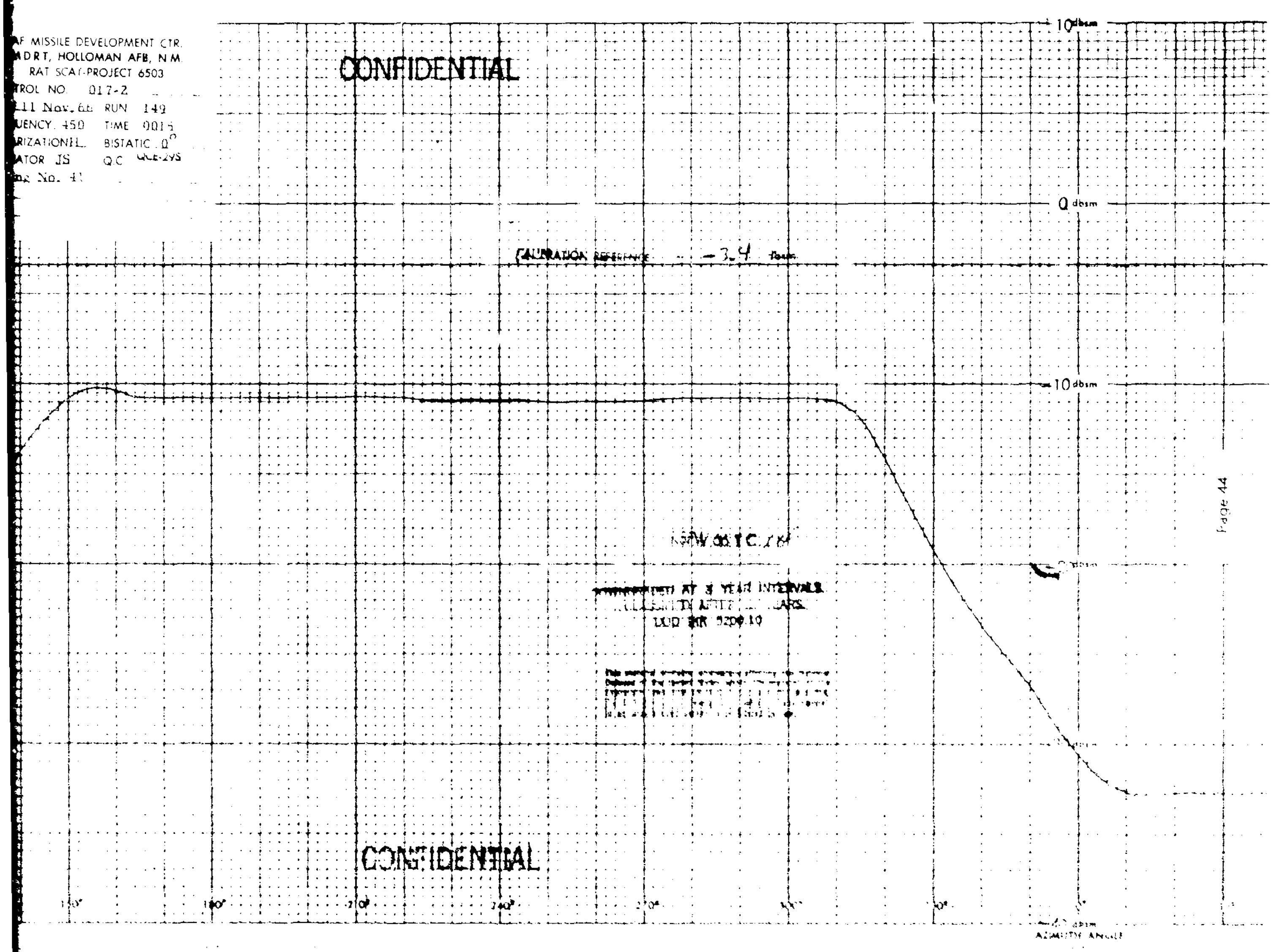

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11 Nov. 66 RUN 149
UENCY 450 TIME 0015
RIZATION HL BISTATIC 0°
ATOR JS Q.C
CONFIDENTIAL
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0 dbsm
CALIBRATION REFERENCE -3.4
10 dbsm
Page 44
AT 3 YEAR INTERVALS
DOD DIR 5200.10
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210°
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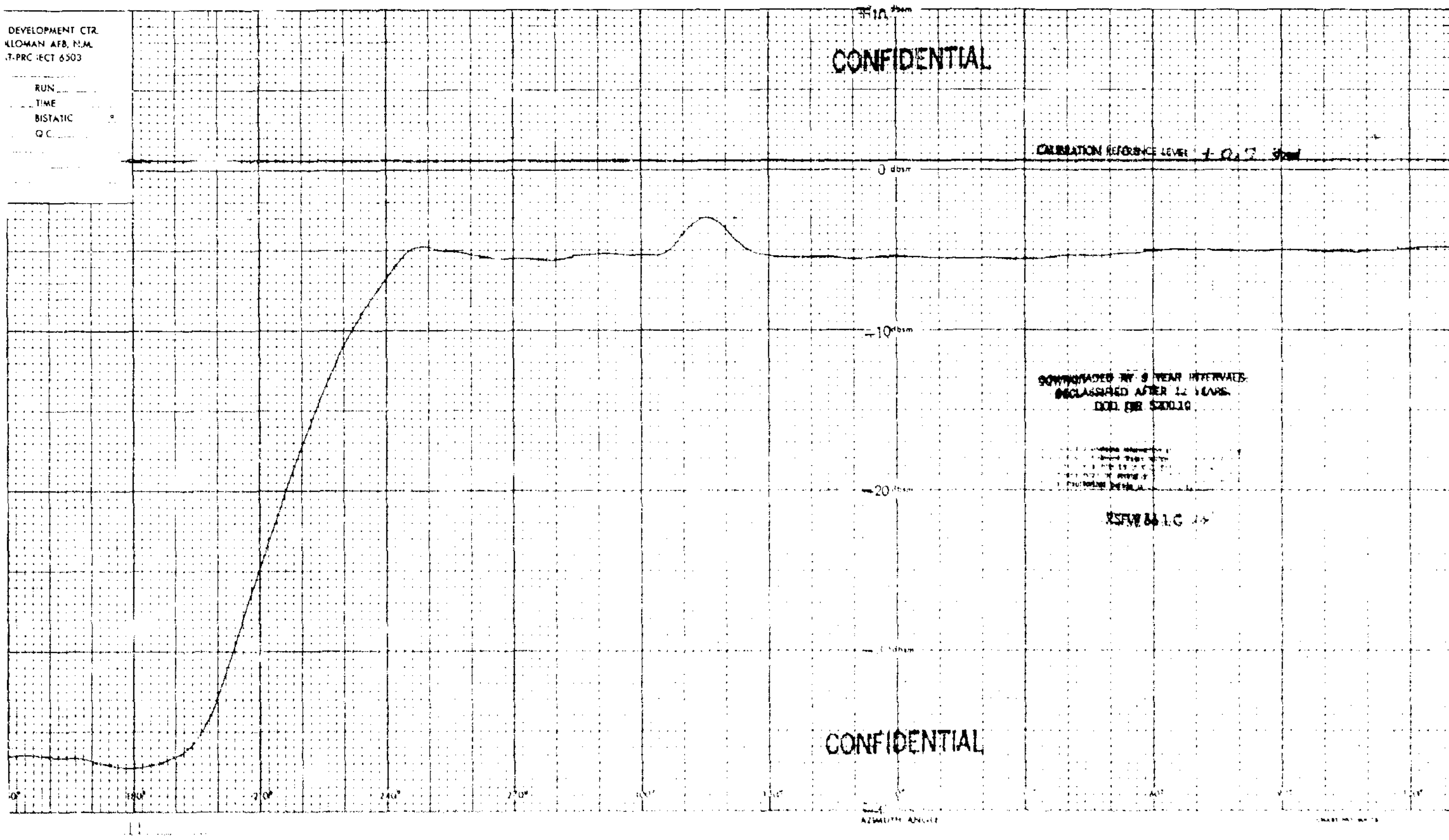
270°
AZIMUTH ANGLE

2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LOMAN AFB, N.M.
PROJECT 6503
RUN
TIME
BISTATIC
Q C
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-10 dbm
DOWNGRADED AT 3 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS.
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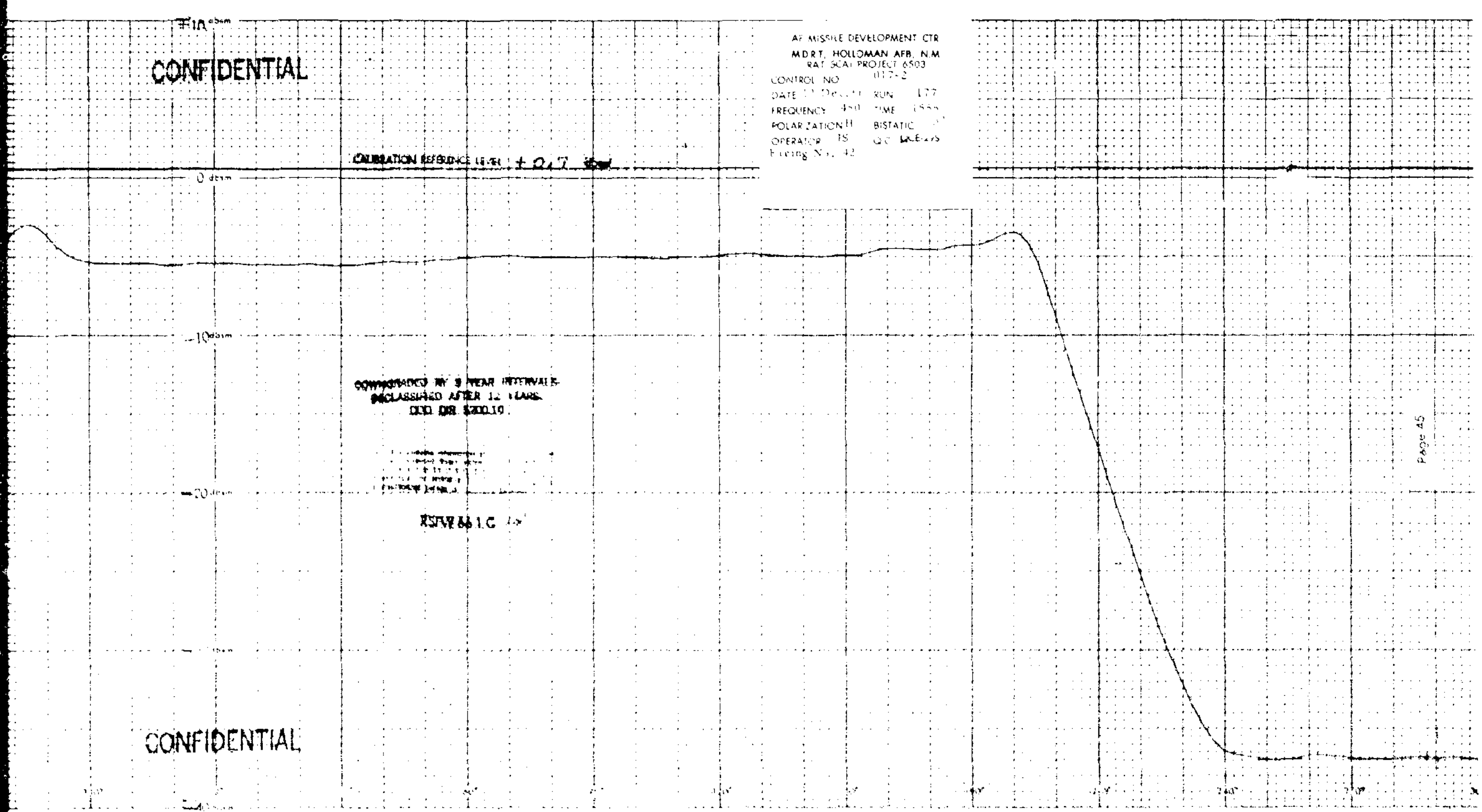

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RUN
FREQUENCY
TIME
POLARIZATION H
BISTATIC
OPERATOR JS
Q.C.
Firing No. 42
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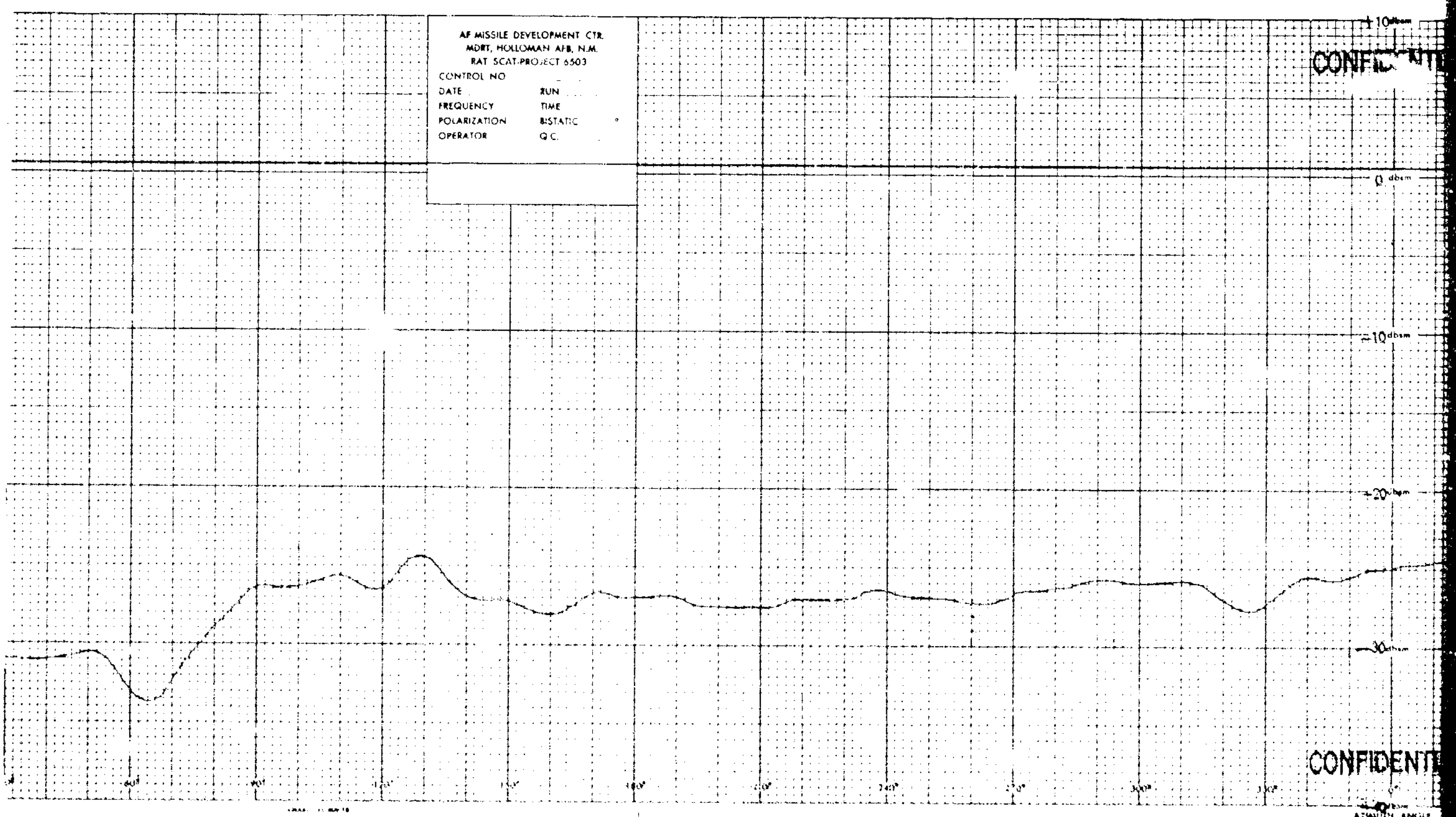
CONFIDENTIAL
Page 45

2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MDRT, HOLLOMAN AFB, N.M.
RAT SCAT-PROJECT 6503
CONTROL NO
DATE
RUN
FREQUENCY
TIME
POLARIZATION
BISTATIC
OPERATOR
Q.C.
+10 dbsm
0 dbsm
−10 dbsm
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AZIMUTH ANGLE
CONFIDENTIAL

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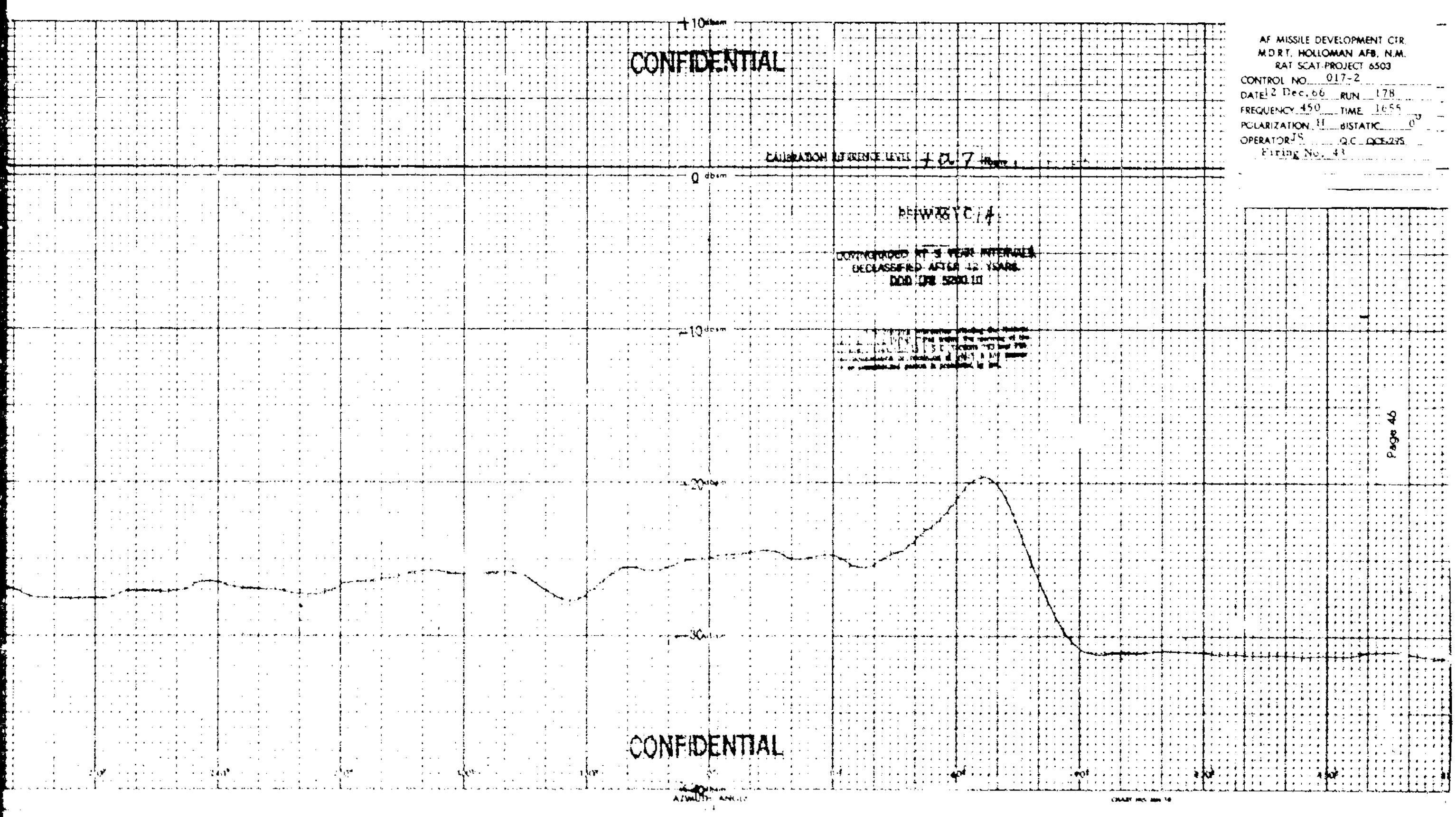
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CONTROL NO. 017-2
DATE 12 Dec. 66 RUN 178
FREQUENCY 450 TIME 1655
POLARIZATION H BISTATIC 0°
OPERATOR JS Q.C. QCE-275
Firing No. 43
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-10 dbsm
-20 dbsm
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DOWNGRADED AT 3 YEAR INTERVALS
DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10
Page 46
CONFIDENTIAL

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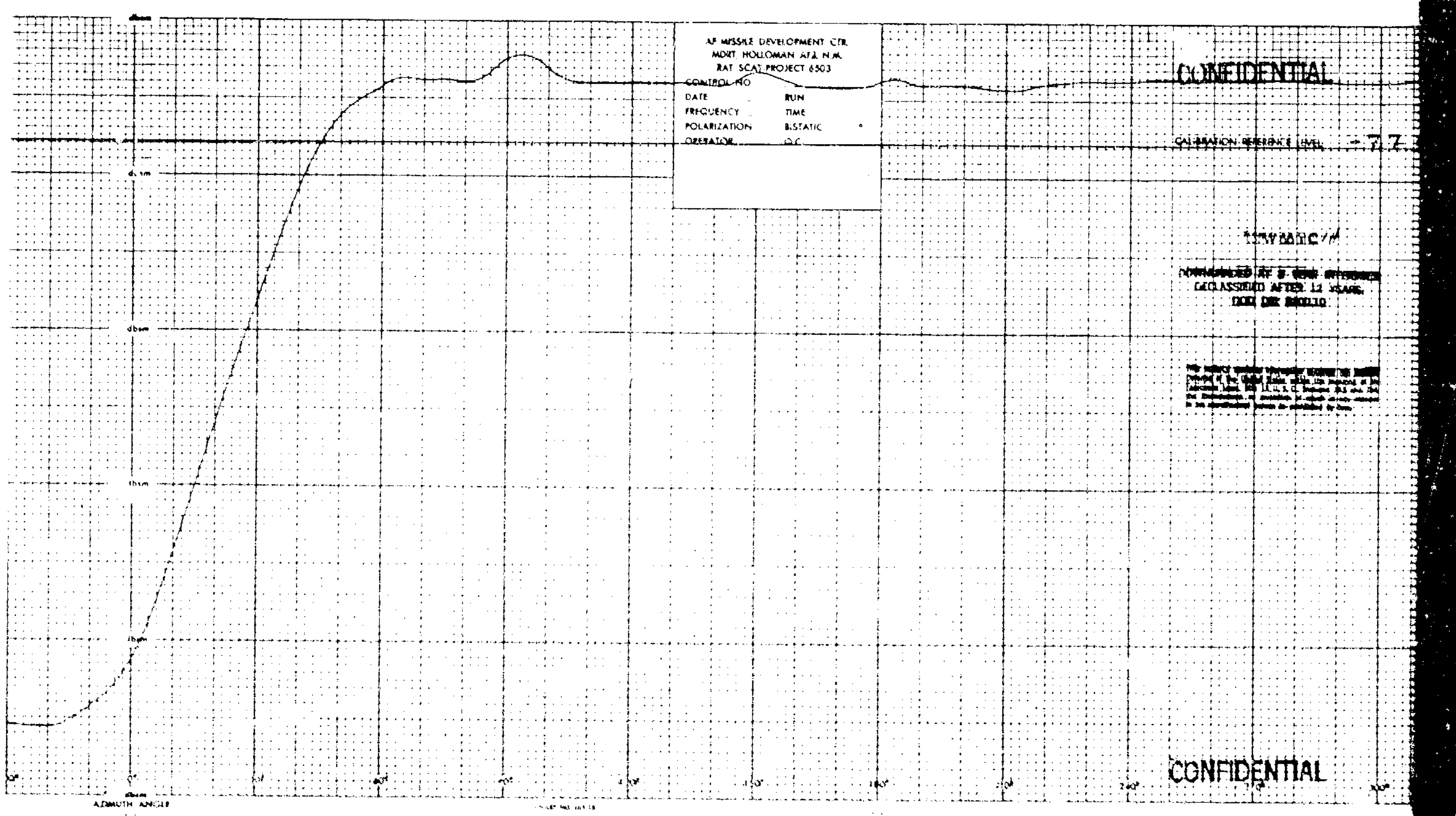
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MDRT HOLLOMAN AFB N.M.
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CONTROL NO
DATE
RUN
FREQUENCY
TIME
POLARIZATION
BISTATIC
OPERATOR
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CONFIDENTIAL
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AZIMUTH ANGLE
CONFIDENTIAL

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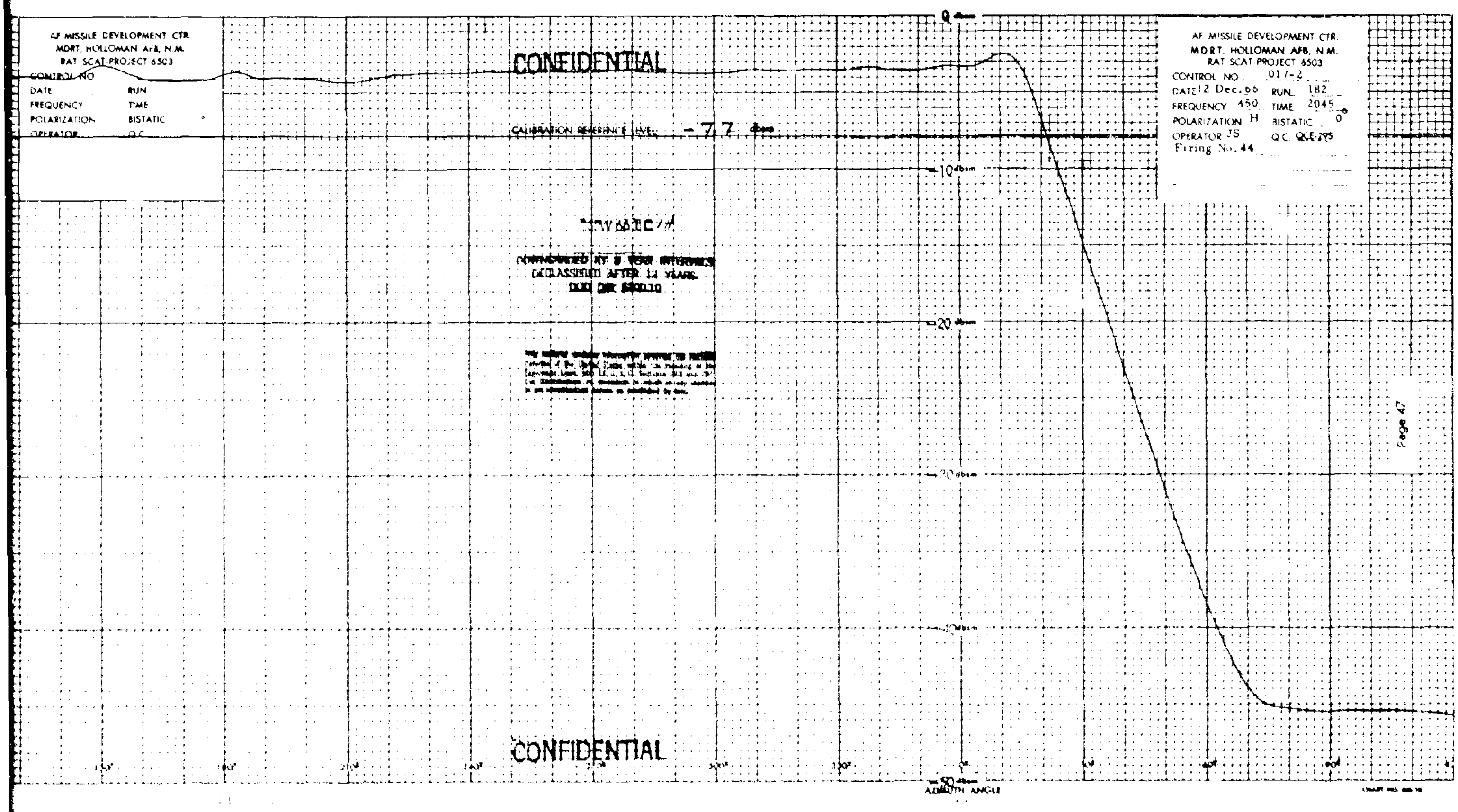
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CONTROL NO
DATE
RUN
FREQUENCY
TIME
POLARIZATION
BISTATIC
OPERATOR
Q.C.
CONFIDENTIAL
CALIBRATION REFERENCE LEVEL -77 dbm
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DECLASSIFIED AFTER 12 YEARS
AF MISSILE DEVELOPMENT CTR.
MDRT, HOLLOMAN AFB, N.M.
RAT SCAT PROJECT 6503
CONTROL NO. 017-2
DATE 12 Dec.66
RUN 182
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OPERATOR JS
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Page 47
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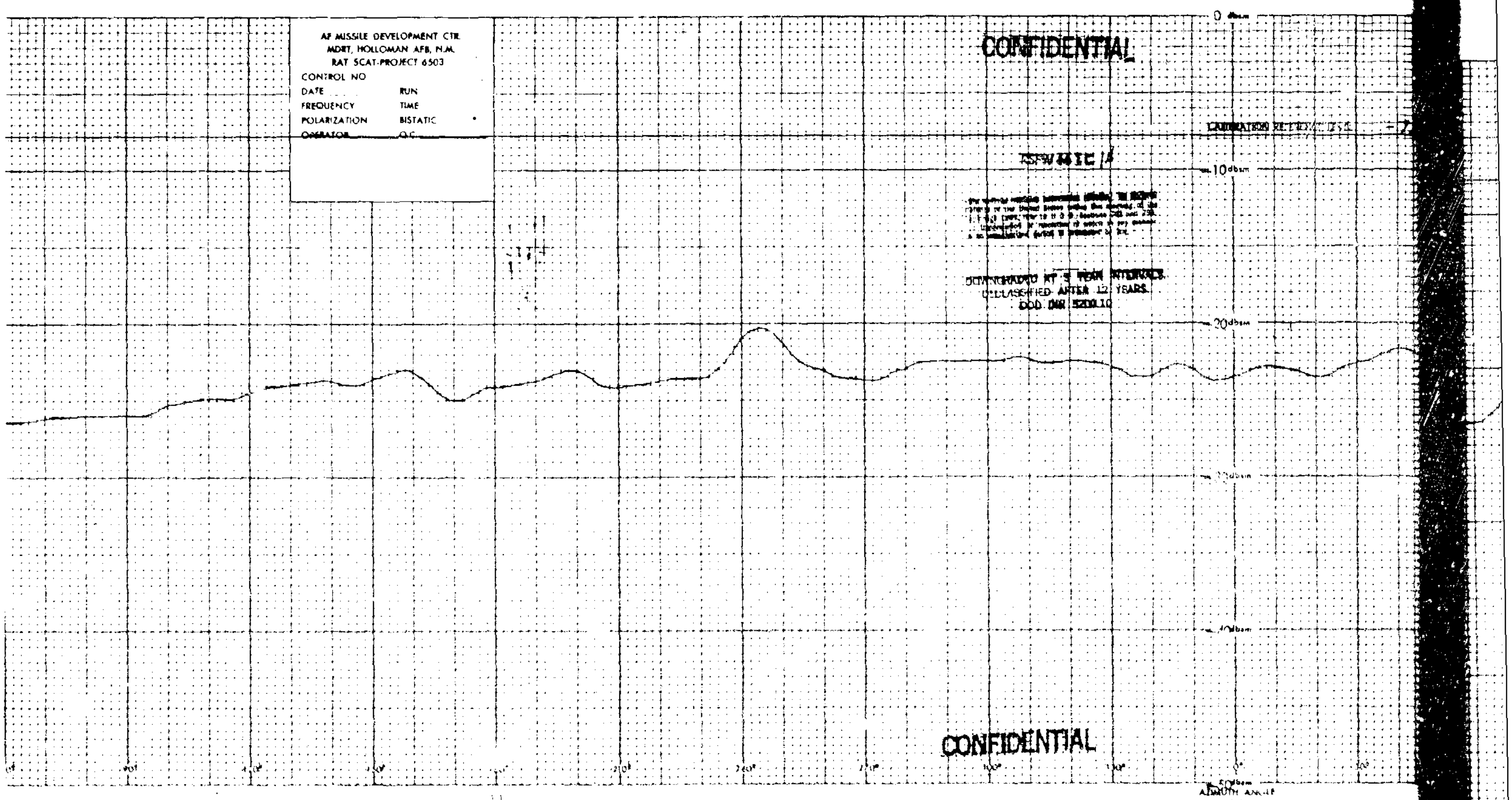
AZIMUTH ANGLE

2



AF MISSILE DEVELOPMENT CTR
MDRT, HOLLOMAN AFB, N.M.
RAT SCAT-PROJECT 6503
CONTROL NO
DATE
RUN
FREQUENCY
TIME
POLARIZATION
BISTATIC
CONFIDENTIAL
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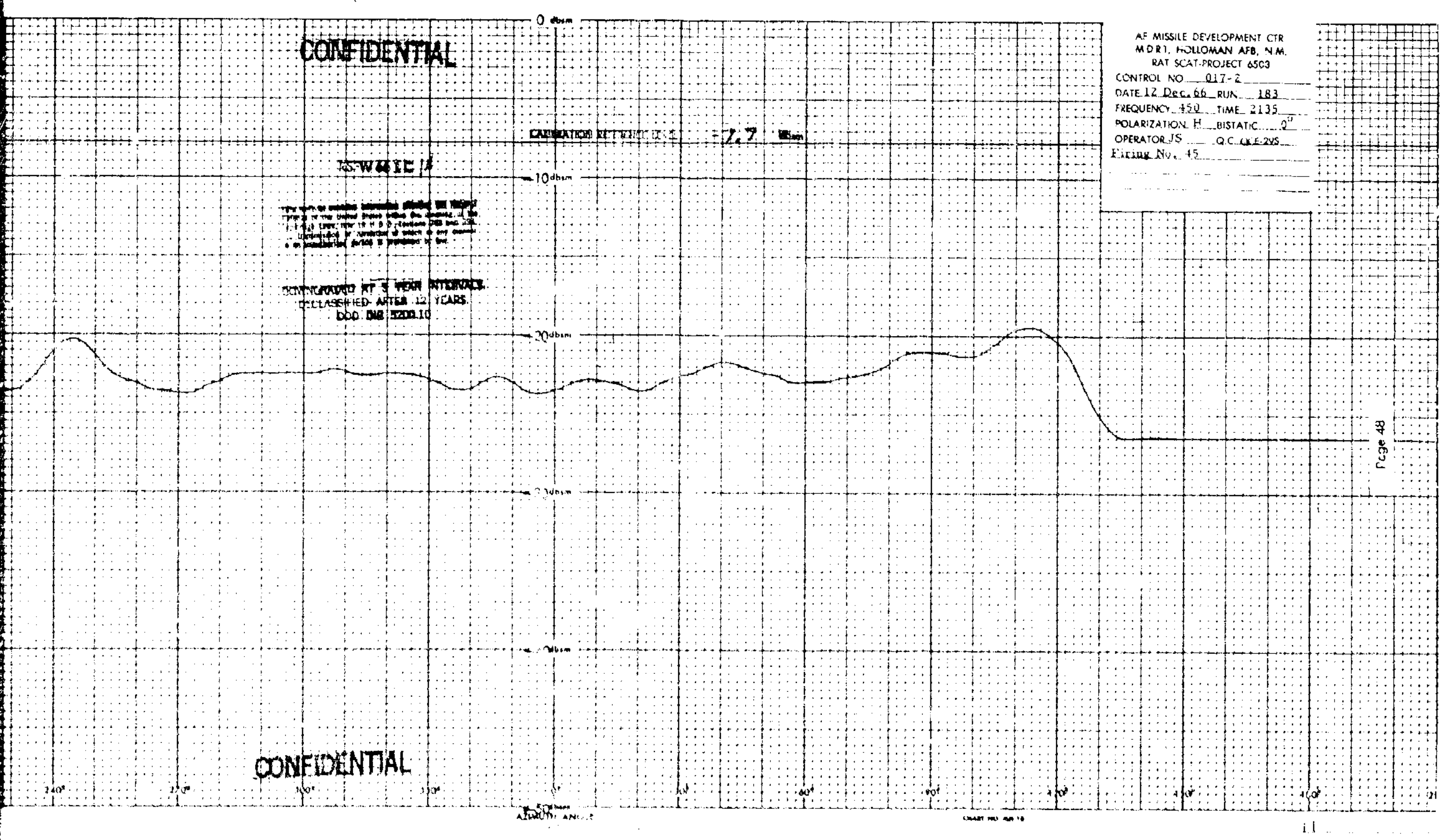
CONFIDENTIAL

1


CONFIDENTIAL
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-7.7 dBsm
10 dbsm
DOWNGRADED AT 3 YEAR INTERVALS.
DECLASSIFIED AFTER 12 YEARS.
DOD DIR 5200.10
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AF MISSILE DEVELOPMENT CTR
MDR1, HOLLOMAN AFB, N.M.
RAT SCAT-PROJECT 6503
CONTROL NO 017-2
DATE 12 Dec. 66 RUN 183
FREQUENCY 450 TIME 2135
POLARIZATION H BISTATIC 0°
OPERATOR JS
Firing No. 45
Page 48
CONFIDENTIAL
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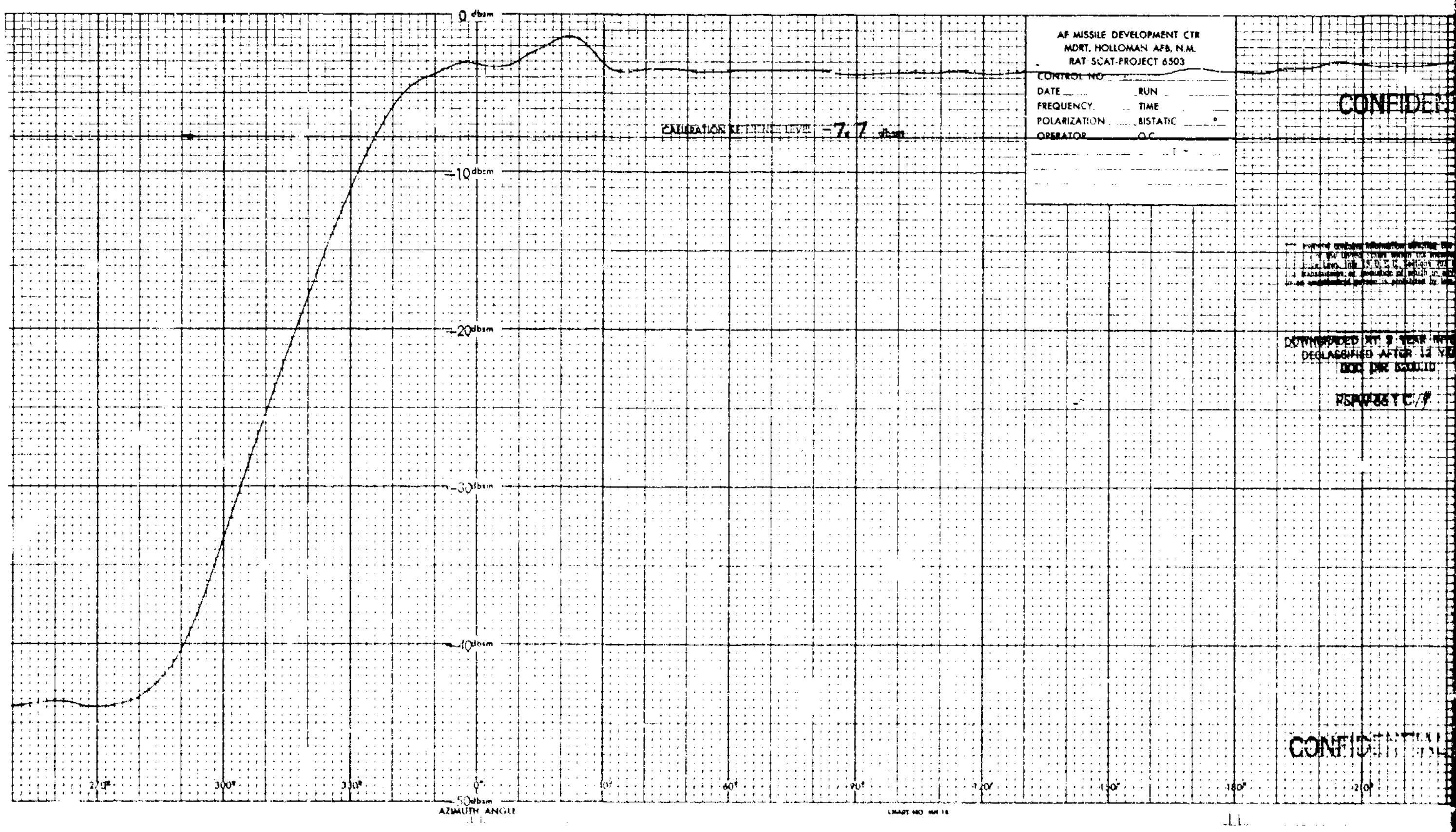
300°
60°

2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OPERATOR
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-50 dbsm
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180°
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AZIMUTH ANGLE
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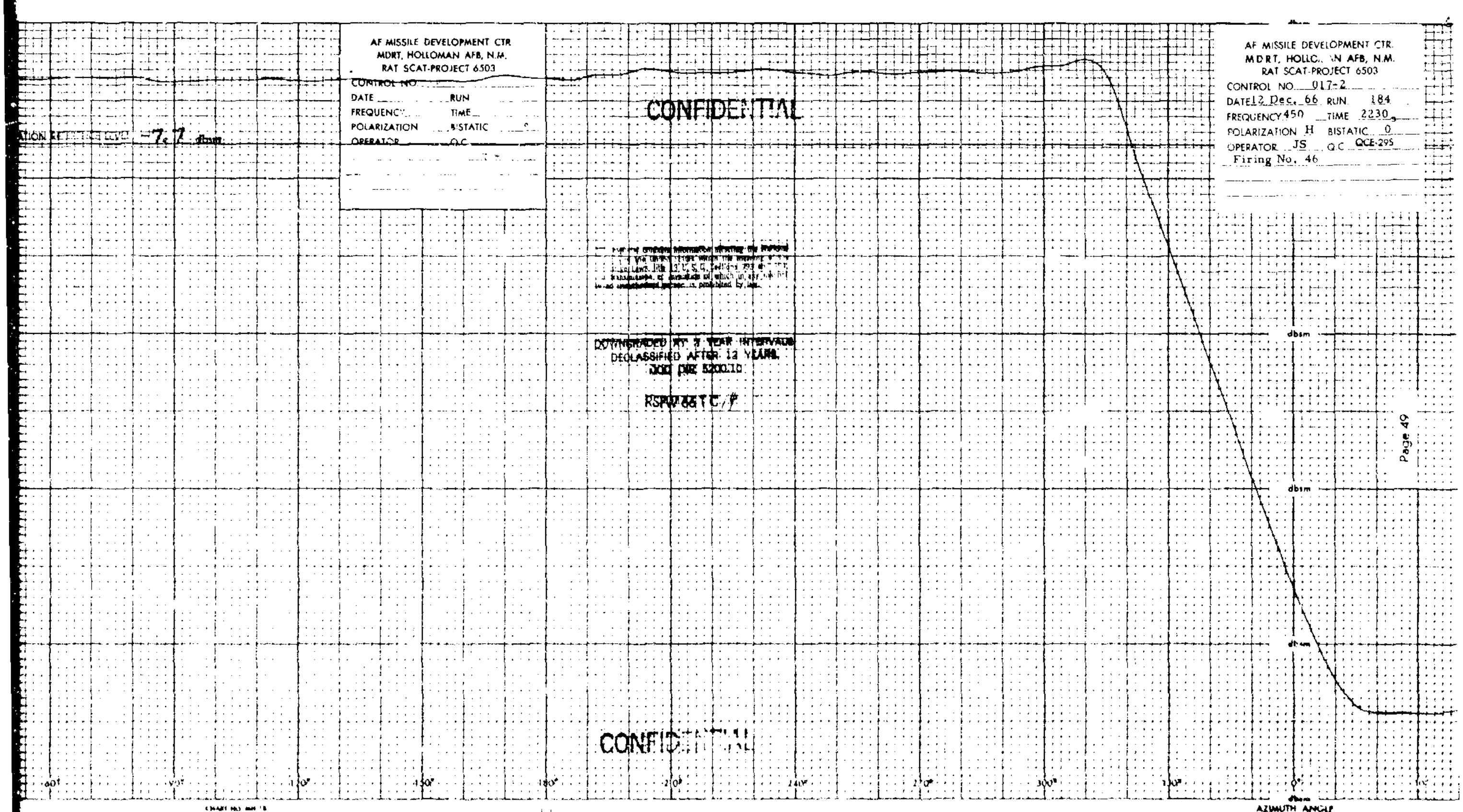
CONFIDENTIAL

1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Page 49
dbsm
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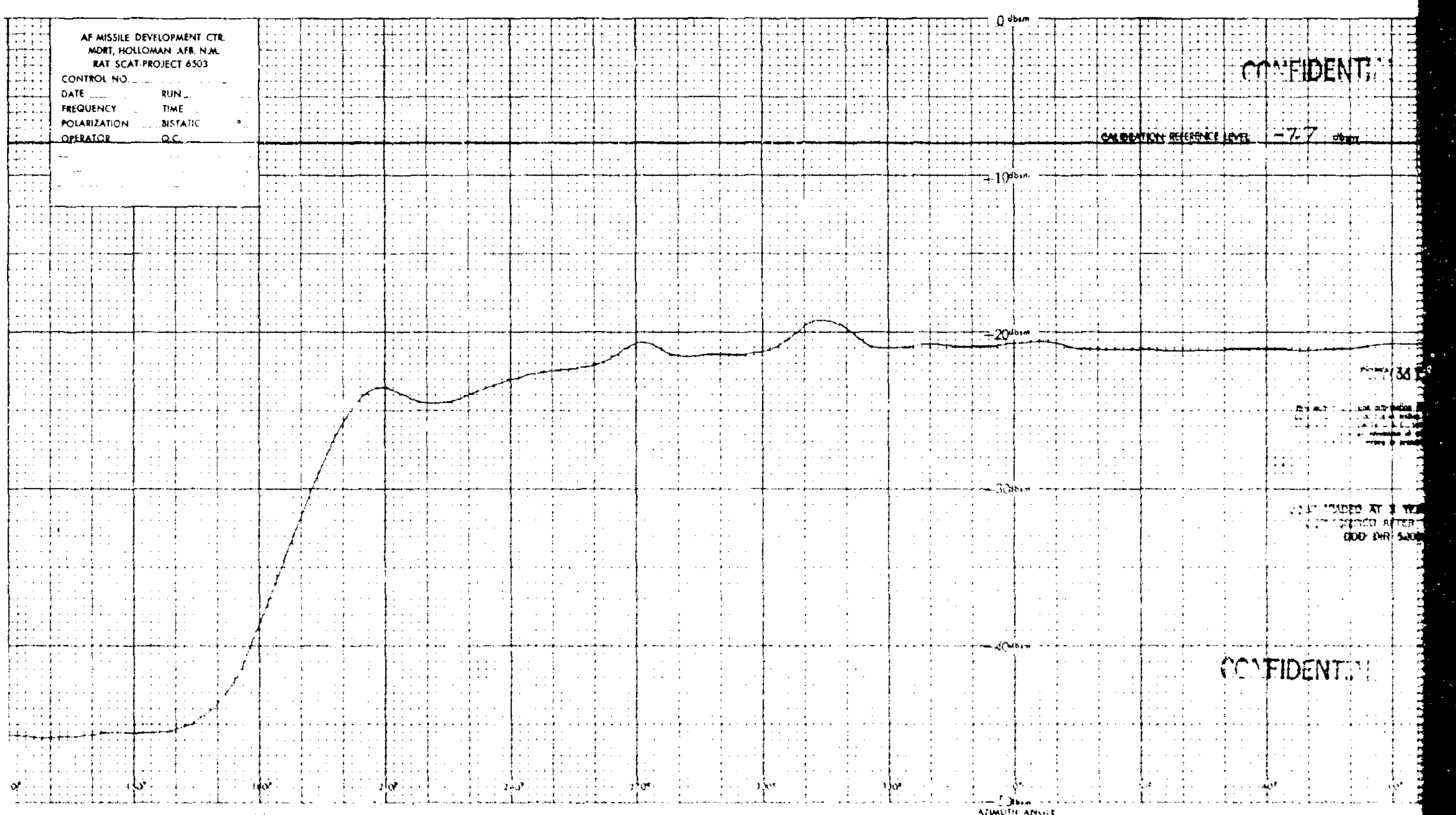
AZIMUTH ANGLE

2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CALIBRATION REFERENCE LEVEL -7.7 dbm
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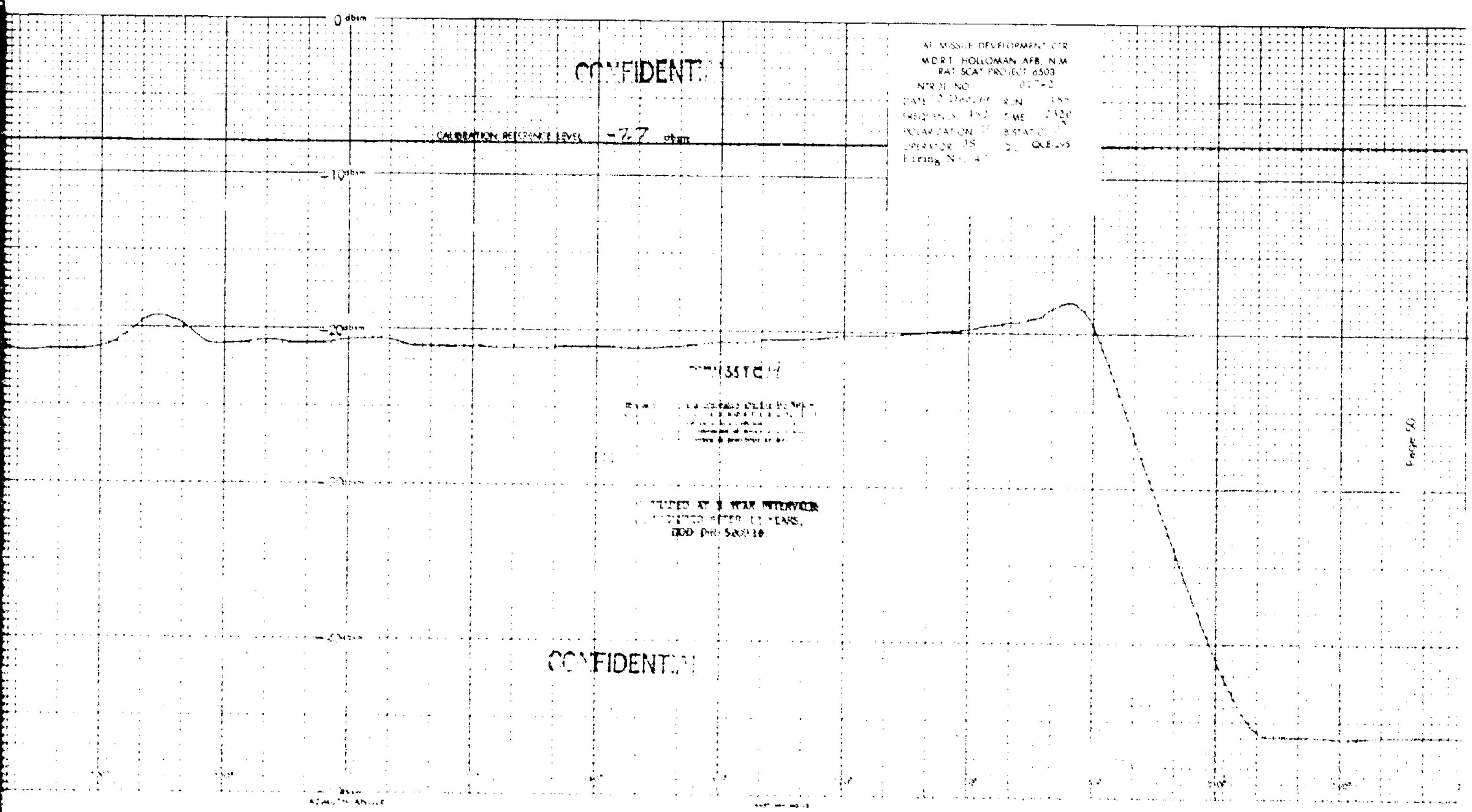
-50 dbm
AZIMUTH ANGLE
CONFIDENTIAL

1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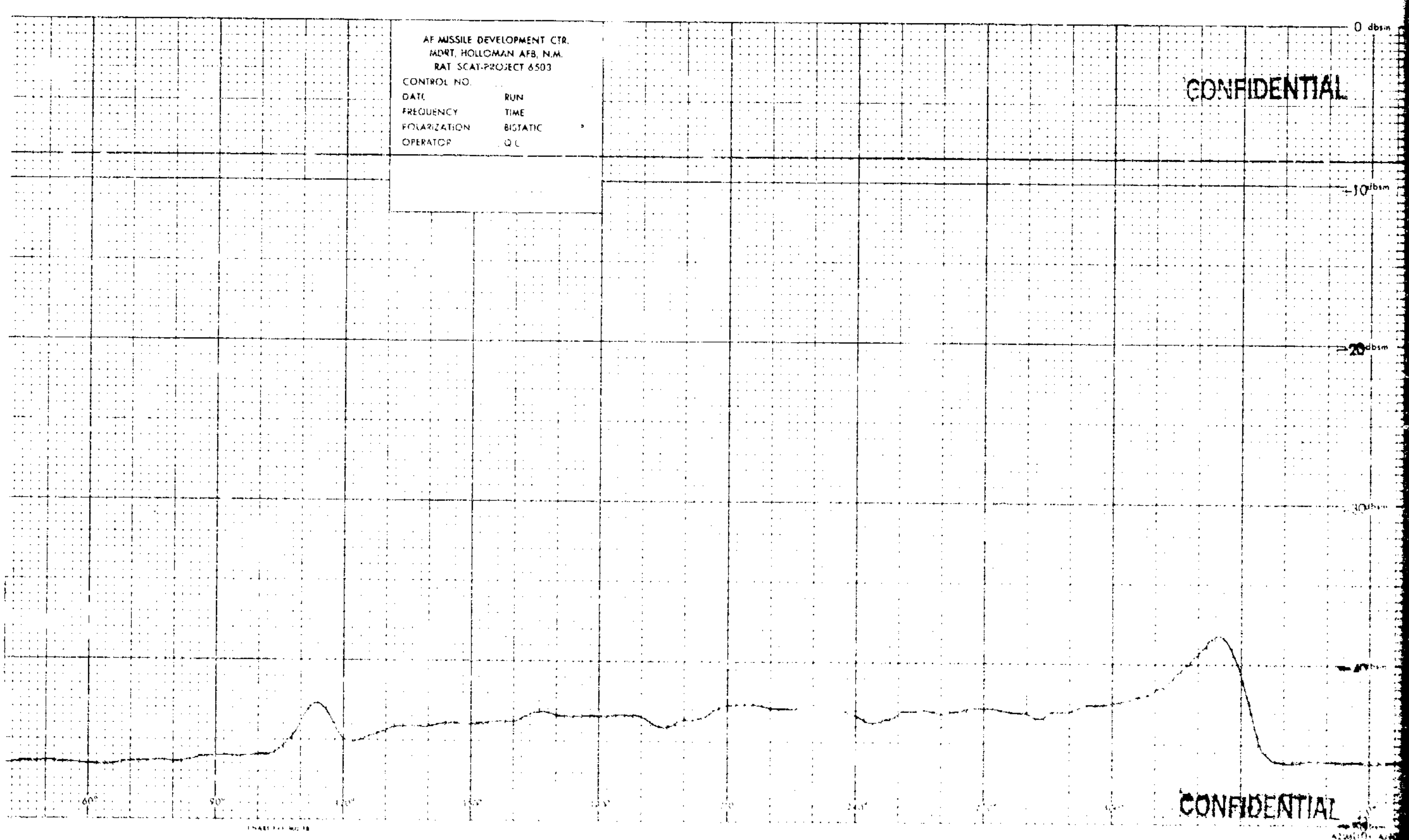
RAT SCAT PROJECT 6503
CONFIDENTIAL

2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RAT SCAT-PROJECT 6503
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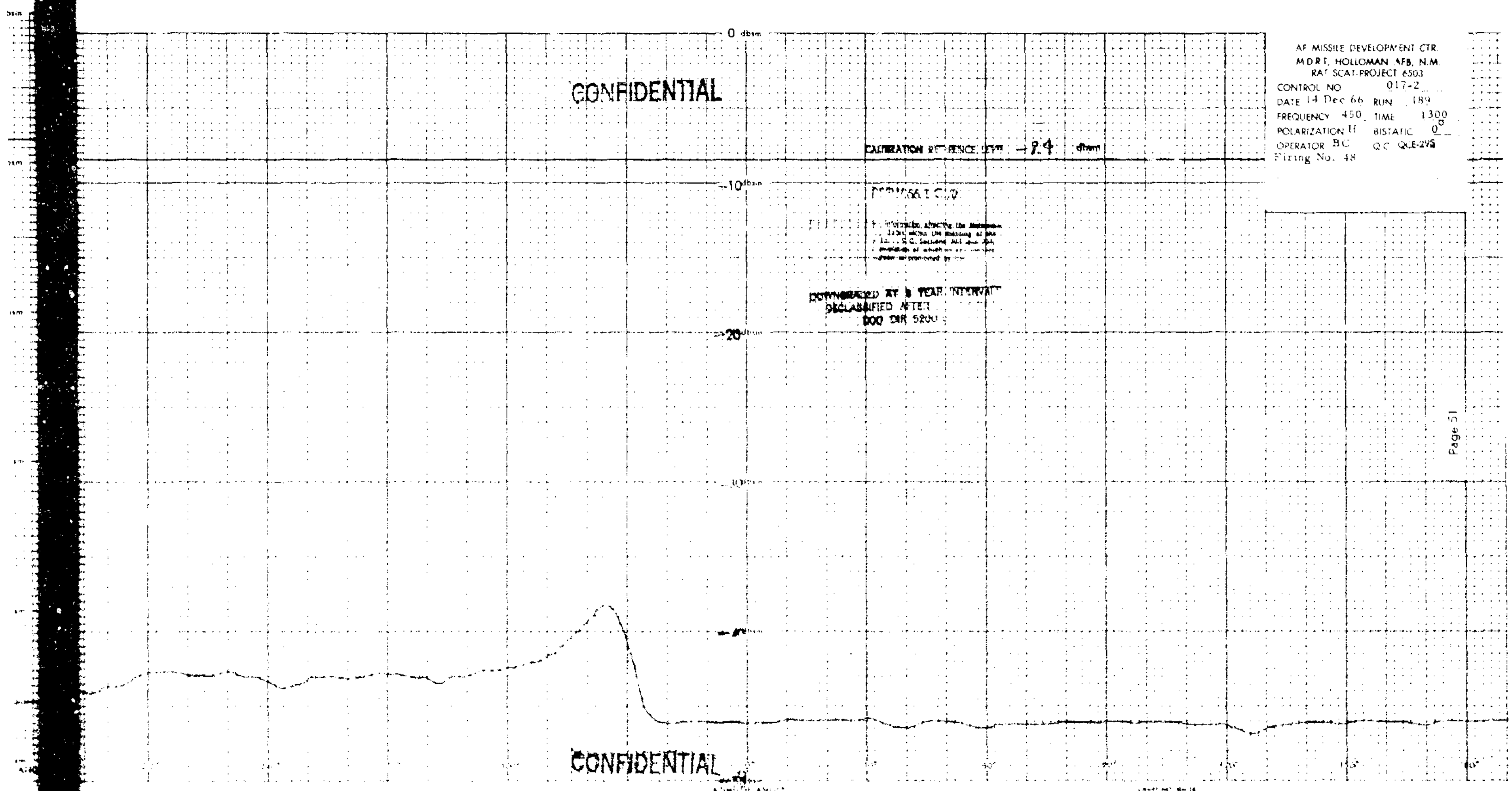
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DOWNGRADED AT 3 YEAR INTERVALS
DECLASSIFIED AFTER
DOD DIR 5200
-20 dbsm
AF MISSILE DEVELOPMENT CTR.
MDRT, HOLLOMAN AFB, N.M.
RAT SCAT-PROJECT 6503
CONTROL NO 017-2
DATE 14 Dec 66 RUN 189
FREQUENCY 450 TIME 1300
POLARIZATION H BISTATIC 0°
OPERATOR BC QC QLE-295
Firing No. 48
Page 51
CONFIDENTIAL

2

APPENDIX A

SITE INTRODUCTION

General

RAT SCAT is a static ground plane radar cross section measurement site, located on Alkali Flats near Holloman Air Force Base, New Mexico. It is authorized by the DOD for use by governmental agencies. It is under the auspices of Air Force Missile Development Center, HAFB, New Mexico.

A ground plane range utilizes radar energy reflected from the earth as well as radar energy traveling directly to the target through the atmosphere. When the antennas and target are adjusted to proper heights, coherent phase addition of these electromagnetic waves into a flat wave front, enhances the system sensitivity. Radar returns from objects near the earth's surface are reduced thus suppressing target area interference. Target area interference is reduced further through the use of special polyfoam mounting platforms, radar absorptive materials (RAM), and rotators located below the earth's surface (in pits).

Pulsed transmitters are employed to enable utilization of the range gated receiving system, which can selectively measure radar returns from the target area or the range displaced transfer standard. Background interference outside the target range is eliminated by range gating. Operation without background cancellation is therefore practical.

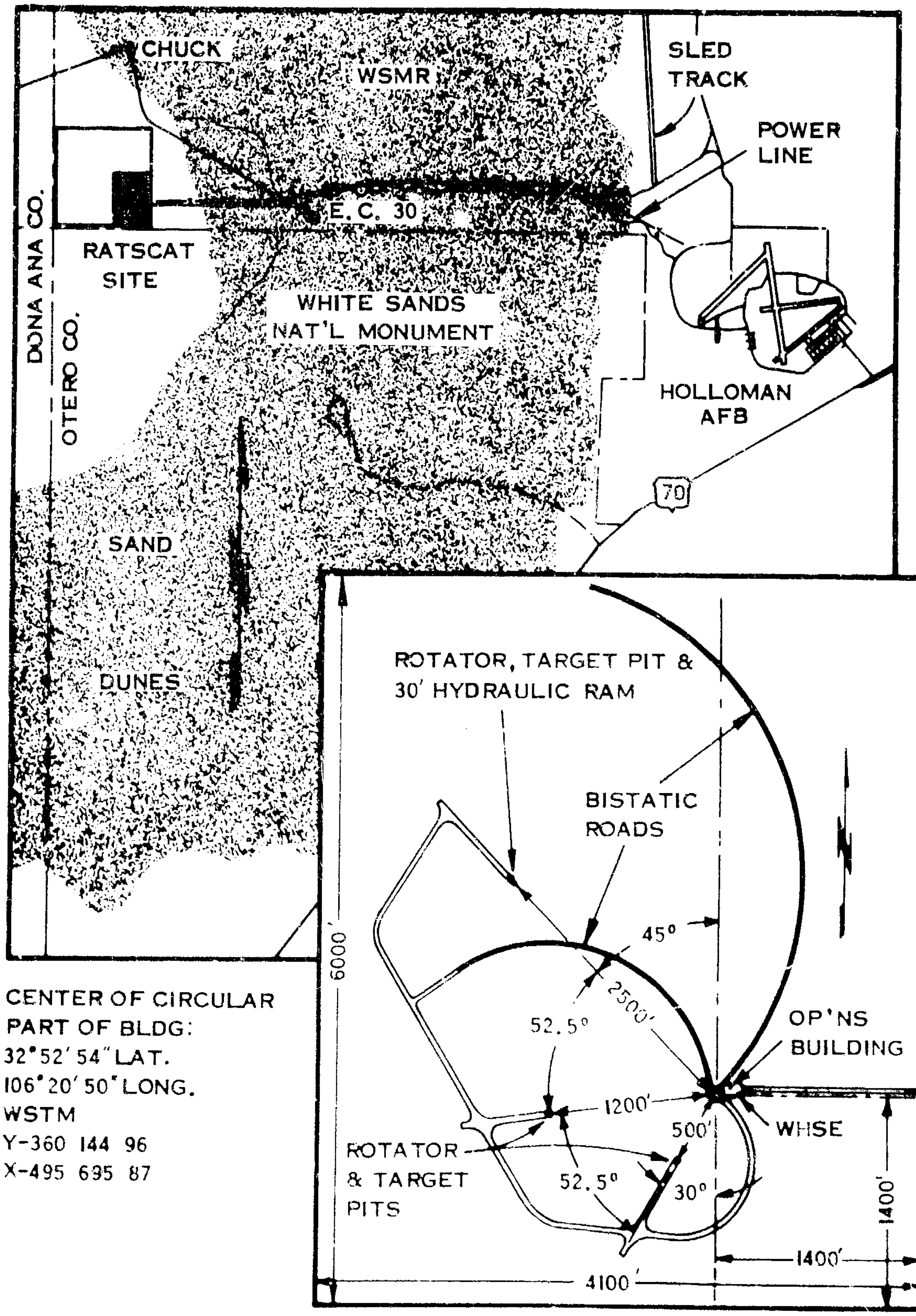
Capabilities

The RAT SCAT electronic equipment and controls are housed in a permanent building. Three separate range lengths (458 feet, 1158 feet, and 2458 feet) are provided for range variation as shown in Figure A-1. This allows the use of convenient antenna and target heights while satisfying the far field criterion for most targets. (Special 40-foot antenna towers are attached to the building for antenna height positioning.) Further versatility is provided by two mobile equipment vans, one for monostatic range length variation and one for bistatic measurements. A duplicate set of control and data consoles in the main building enables simultaneous operation of any two of the three ranges. A summary of the RAT SCAT characteristics is contained in Table A-1.

Calibration

The normal method of calibration at RAT SCAT is to mount a primary standard (precision sphere) scatterer with radar cross section and record the corresponding signal level. Then the return from another secondary standard (corner or Luneberg lens) scatter displaced in range is recorded as a transfer standard. Both the precision standard return and the transfer standard return are recorded on the same plot. Thereafter, radar cross section calibration is determined by referencing the transfer standard return for every run. Thus every run is recalibrated. The comparisons of primary and transfer standards accomplished before and after each measurement series are identified respectively as calibration and post-calibration. If the direct ratio of primary to secondary readings is not maintained before and after the measurement series, then all runs between are invalid and must be repeated.

The calibration reference level marked on each data plot is related to the transfer standard level. This reference level may under controlled conditions differ from the actual transfer standard signal level since precision calibrated attenuation is sometimes inserted in the receiver line. When such attenuation is inserted, returns from the transfer standard are reduced to a level compatible with the scale used for the target measurements. The 50 db dynamic range of the plot is placed to include the range



CENTER OF CIRCULAR
PART OF BLDG:
32°52′54″ LAT.
106°20′50″ LONG.
WSTM
Y-360 144 96
X-495 695 87

FIGURE I: RATSCAT PROJECT 6503

TABLE A-1 RAT SCAT CHARACTERISTICS OF ELECTRONIC EQUIPMENT

Power Output	1 KW minimum
Pulse Width	0.1 to 1.0 microsecond
Pulse Repetition Frequency	500 to 5000 pps
No. of Receiving Systems	Two per Band, (one monostatic and one bistatic)
Receiver Minimum Detectable Signal	-94 to -106 dbm (proportionate to frequency)
Receiver Bandwidth	2 or 10 mc (selectable)
Range Gate Width	0.1 to 1.0 microsecond (50 to 500 feet)
Dynamic Range	50 db
Linearity	±0.5 db
Equipment Stability	0.1 db/hour (Average)
Analog Data Format	Polar and rectangular plots of cross section and phase vs aspect angle
Digital Data Format	Punched paper tape recorded at 0.1 - to 4.0 degree azimuth increments
Antennas	3-, 6-, 10-, and 16-foot parabolic dishes (smaller and larger dishes (1.5 to 30-foot for special tests)
Antenna Feeds	Log periodic and horns all with VSWR less than 2.0 to 1.0
Polarization	Horizontal, vertical, circular, elliptical in any cross combination of transmitting and receiving configuration.
Background Level	As low as -80 dbsm (frequency dependent)
Background Reduction	Tuned columns and vector substraction by using phase and amplitude measurements to reduce background by 20 db
Phase Measurement	Unique RAT SCAT capability for vector subtraction or scattering matrix applications. Band 4 only.
Azimuth Resolution	0.1 degree
Maximum Target Weight	10,000 pounds
Target Size	Greater than 60-foot length
Bistatic capability	458-, 1158-, and 2458-foot range for 0- to 120-degree bistatic angle
Frequency Coverage	100 to 11,500 mc (7 bands)

Band 1 - 100 to 250 mc Band 2 - 250 to 500 mc
Band 3 - 500 to 1000 mc Band 4 - 1000 to 2000 mc
Band 5 - 2000 to 4000 mc Band 6 - 4000 mc to 8000 mc
Band 7 - 8000 mc to 11,500 mc

Range Length	300 feet minimum

Building/Pit 1 - 458 ft Building/Pit 2 - 1158 ft
Building/Pit 3 -2458 ft Monostatic Van/Pits 1,2, or 3 - variable Range length

of returns expected from the vehicle being measured. In some cases 2 runs are necessary to be plotted for direct overlay to include the dynamic range of the vehicle if it exceeds 50 db. Calibration plots are included with the target data when requested by the user.

The sphere calibration plots will not necessarily be straight lines. If the background return is within 20 db of the sphere return, for example, a variation in sphere return of approximately ± 1 db can result. For calibration the sphere is intentionally placed at least 1/2 wavelength off the center of table rotation to insure sufficient phasing with the background return. The average sphere return is then chosen for a calibration level. This avoids the peak errors involved with coherent addition of sphere return and background return and allows the minimum errors involved with non-coherent addition of the returns. This is indicated in Figure A-2.

Operating Procedures

The following step-by-step procedure is standard in obtaining monostatic radar cross section measurements after frequency, feeds, antennas, antenna height, target height, and pit (range length) have been chosen:

1. Calibration - As described in previous section.

2. Horizontal and Vertical Probes (field strength measurements at the target area) - Horizontal probes at the target area have been shown to be redundant for azimuthal boresighting. For this reason, these probes are taken only upon request for examination of near field effects. Vertical probes are taken at the target area to determine power variation as a function of target height. If necessary, antenna height is varied to obtain an acceptable vertical probe which then necessitates a new calibration.

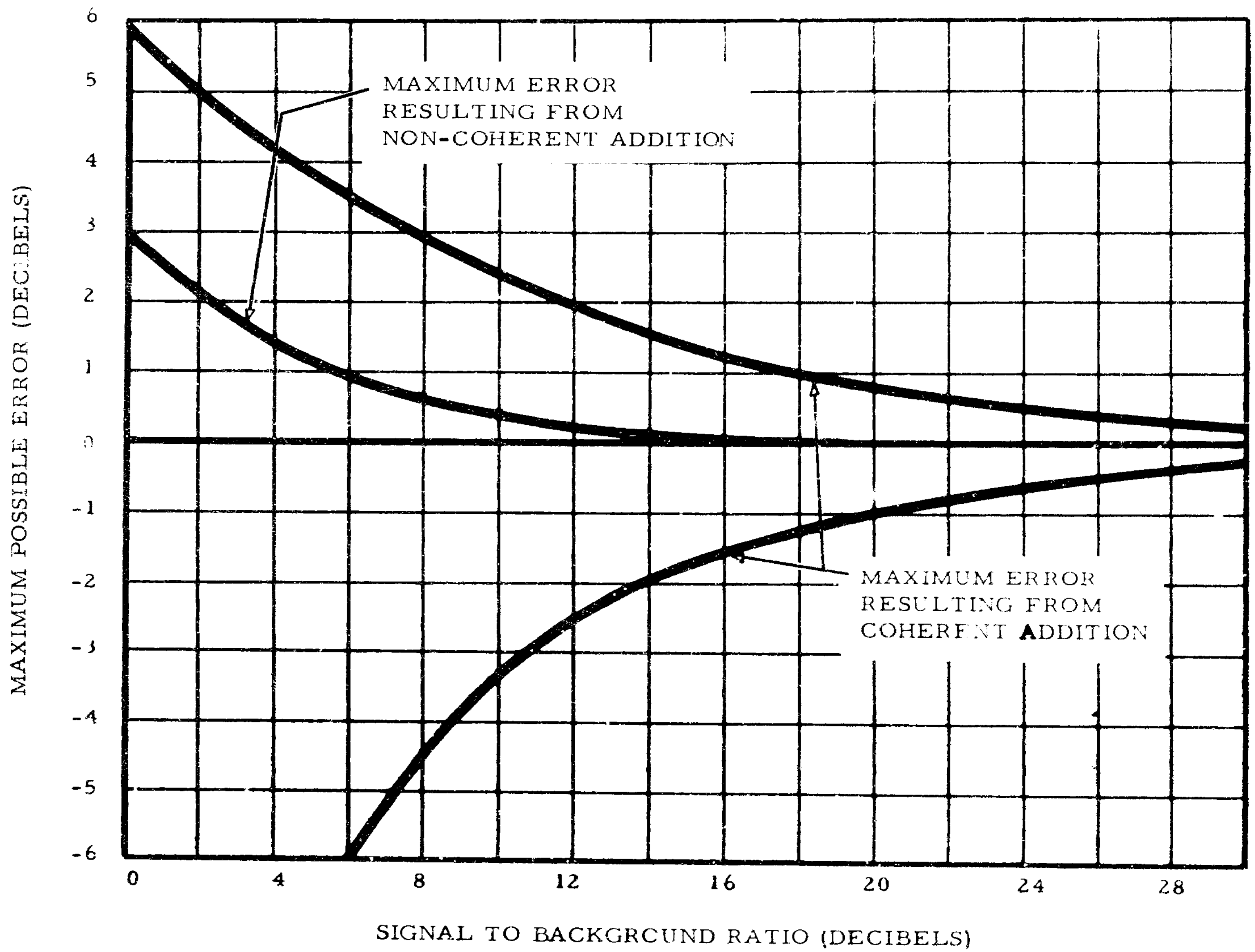


FIGURE A-2 PLOT OF ERROR INDUCED BY BACKGROUND INTERFERENCE

3. Background - The background level with the target mount in place is measured in each polarization to be used.

4. Measurement - The measurement is made with the vehicle in the position previously occupied by the primary standard.

5. Calibration - The primary calibration is repeated to verify calibration (post cal.).

APPENDIX B

TARGET ORIENTATION AND DATA FORMAT

Coordinate System

The coordinate system described herein has been adopted as a standard for RAT SCAT operations. The system is referenced both to the vehicle being measured and to the measurement site.

Vehicle Reference

A three-axis system, referenced to an arbitrary vehicle, is illustrated in Figure B-1. In this system three mutually perpendicular planes (yaw, pitch, and roll) are passed through the vehicle so that the pitch and yaw planes mutually intersect on the longitudinal axis of the vehicle. These planes remain fixed with respect to the vehicle, regardless of vehicle rotation with respect to the radar or ground plane. The yaw plane, which includes the pitch azis and the roll axis, is numbered from 0 degrees to 360 degrees in a clockwise direction when the vehicle is viewed from the above. The nose-on aspect corresponds to 0 degrees, the starboard side of the vehicle corresponds to 90 degrees, and the port side to 270 degrees. The pitch plane, which contains the roll axis and the yaw axis is numbered from 0 degrees to $\pm$ 180 degrees; the $\pm$ 90 degree point is below the center line, and the - 90 degree point is above the center line. The roll plane contains the yaw axis and the pitch axis. It is numbered from 0 degrees to 360 degrees, and the numbers increase in a counterclockwise direction when the vehicle is viewed from the rear.

Site Reference

As previously stated the coordinate system is fixed with respect to the vehicle. It is referenced to the site by means of three index marks. The exact value of any of the three angles is determined by noting the value of the vehicle coordinate opposite the index marks. Index marks

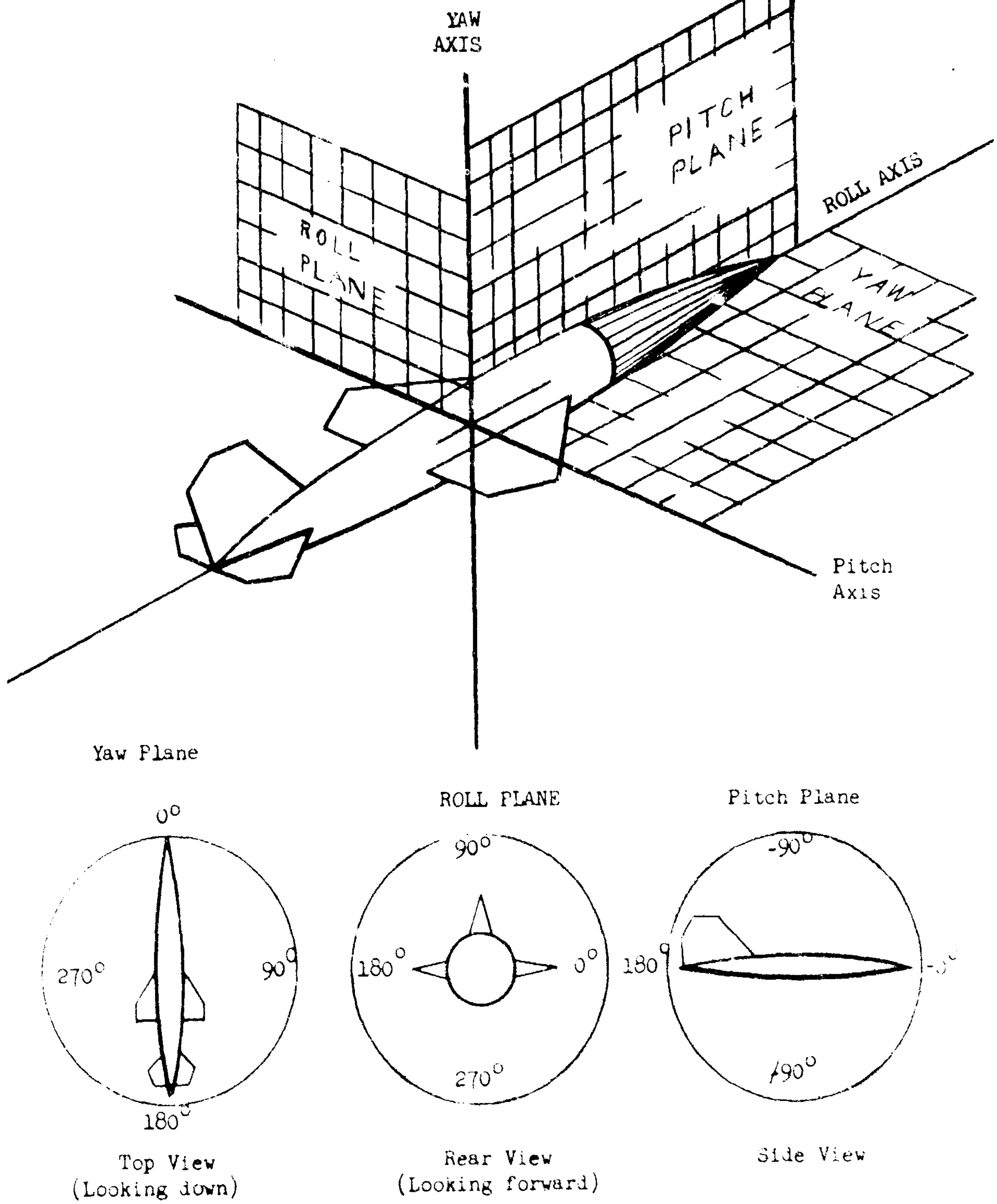


FIGURE B-1 VEHICLE COORDINATE SYSTEM

come from such devices as bubble levels, inclinometers and transits.

As illustrated in Figure B-2, the index for roll angles is normal to the axis of rotation. As illustrated in Figure B-3, the index for pitch angles is normal to the axis of rotation and in line with the apparent source of radiation. For measurements at the RAT SCAT Site, targets can be mounted to provide desired pitch and roll angles.

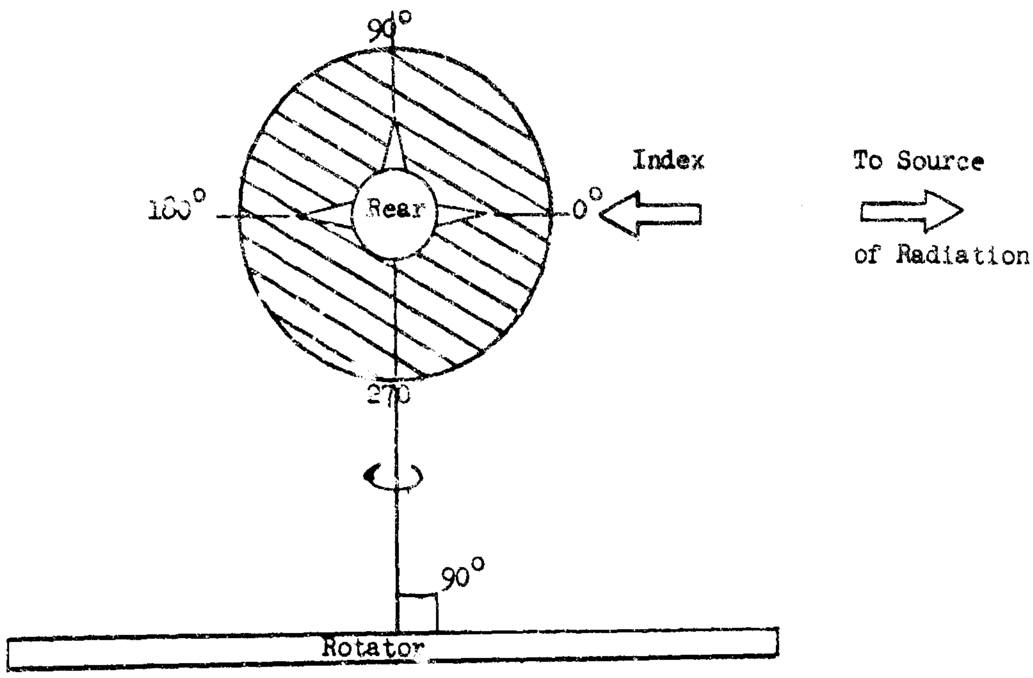
Coordinate System Tilt

For small targets another angle, tilt, can be utilized in recording useful data. This angle, equipment-limited to less than 15 degrees, is formed by the axis of rotation and the normal to the line of sight to the apparent source of radiation. Since, in a ground plane range, radiation can be considered to emanate from a point with zero height directly beneath the antennas, a zero-degree tilted axis of rotation is slightly off the geometrical vertical. This small deviation from the geometrical vertical is neglected in the following discussions.

A target mounted with a pitch angle other than zero displaces the yaw axis from the vertical, but not the axis of rotation. The axis of rotation is displaced from the vertical only when non-zero tilt is employed. Tilting toward the radar is considered positive tilt and away from the radar is negative tilt. For monostatic measurements tilt will be measured in the vertical plane containing the line of sight between the radar and the target. The difference between pitch and tilt is shown in Figure B-4.

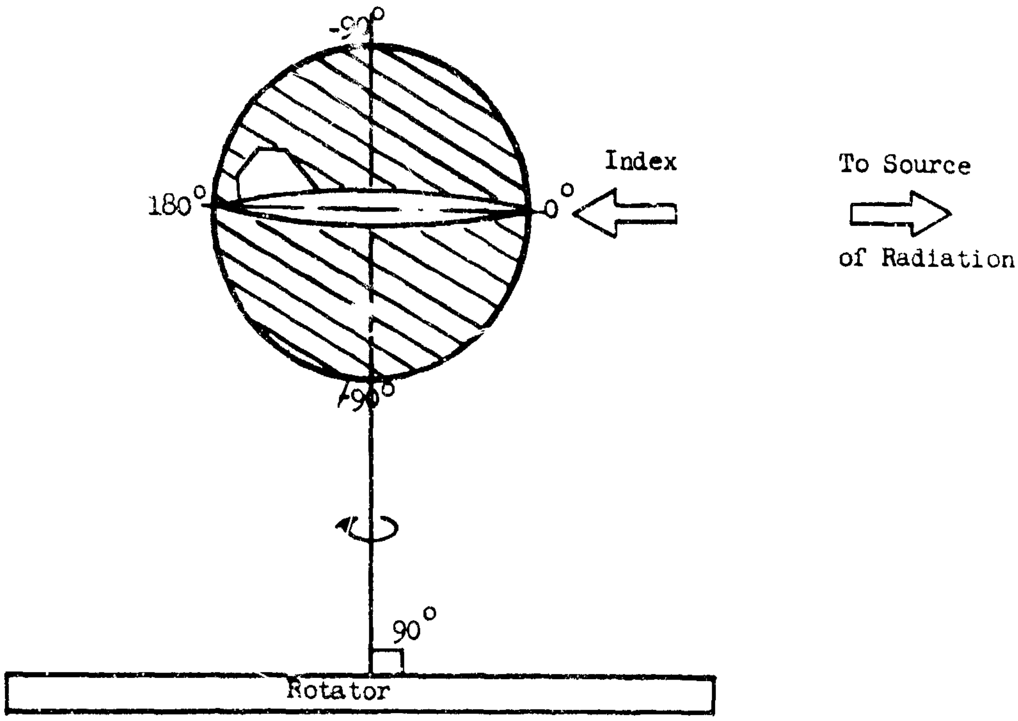
Data Format

Data recorders obtain azimuth angle information by means of precision synchro signals from the position of the rotating table. The line of sight from the antennas to the center of the rotator, as illustrated in



NOTE: The roll scale is fixed to the vehicle. The amount of roll is determined by noting the number of degrees opposite the index. Clockwise rotation of the target (when viewed from the rear) increases the roll angle.

FIGURE B-2 TARGET ORIENTATION - ROLL



NOTE: The pitch scale is fixed to the vehicle.
The number of degrees of pitch is determined
by noting the scale value opposite the index.

FIGURE B-3 TARGET ORIENTATION - PITCH

Figure B-5, indexes azimuth angles. As used here the term azimuth refers to the position of the target rotator table. With zero degrees of pitch and roll, azimuth and yaw are identical. It is standard practice to turn the rotator in a clockwise (cw) direction as viewed from above. Consequently, the azimuth angle varies, for example from 180 degrees (tail-on) to 90 degrees (starboard-side) to 0 degrees (nose-on) to 270 degrees (port-side).

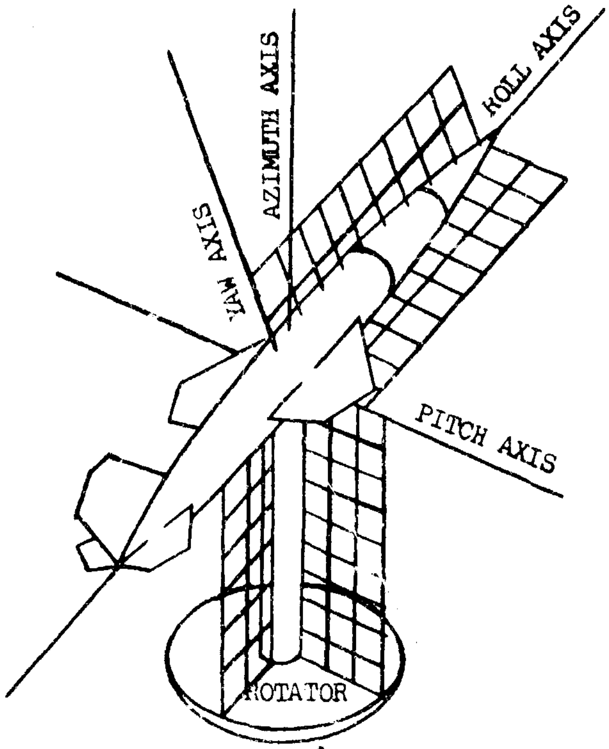
Polar and Rectilinear Plots

Essential information pertinent to each plot is contained in the information block located in the upper right hand corner of the rectilinear plots and in the second quadrant of the polar plots. Each rectilinear plot has the recording of the return from the left side of the vehicle on the left side of the plot, 0 degrees at the center, and the recording of the return from the right side of the vehicle on the right side of the plot; 180 degrees (tail-on) appears at the right and left extremeties of the plot, as shown in Figure B-6. Since the paper moves from left to right under the recorder pen, it should be noted that measurements are limited at 180 degrees in order to obtain continuous measurements on the recorder paper. The table on the polar recorder is rotated in the same directions as the target so the 90-degree point appears on the right side of the polar plot, the 270 degree point on the left, and the zero or 360 degree point at the top of the plot.

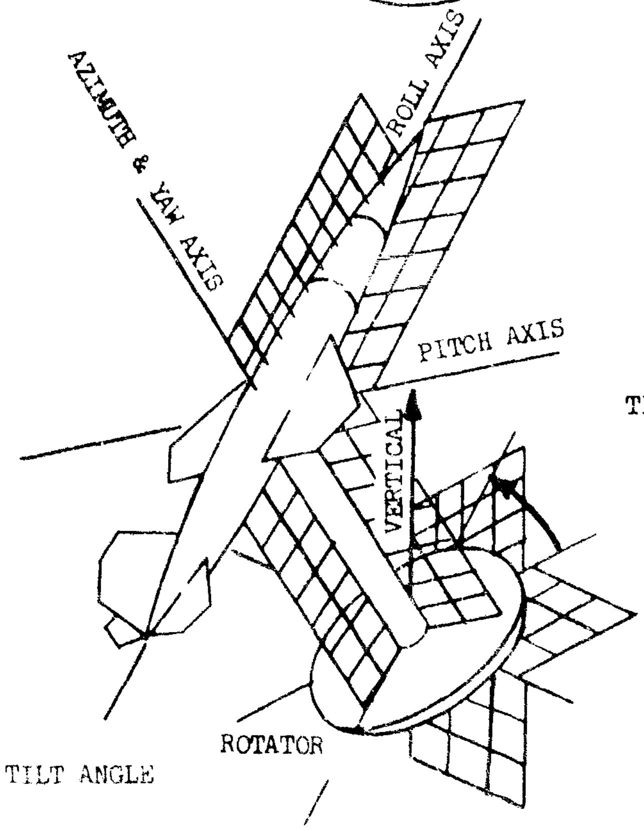
Digital Printouts

At the users request, radar cross section data are available in the digital form of punched paper tapes. The 11/16 inch tape is punched with the standard TELETYPE COMMUNICATIONS (Type 3) code in which 5-bit characters are used. Sigma servo positions, quantitized to tenths of a db, are recorded at specified azimuthal increments (.1,

NOTE: 1) Axis of rotation is always collinear with Azimuth Axis.
2) Nose-on points towards source of radiation in both cases.

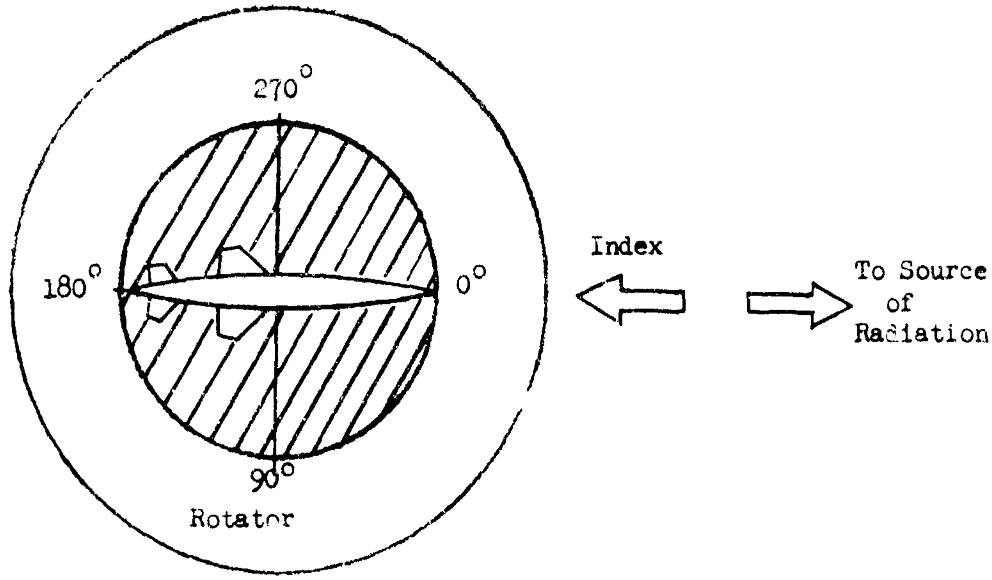


PITCH



TILT

FIGURE B-4 COMPARISON OF PITCH AND TILT ORIENTATIONS



NOTE: The azimuth scale is fixed to the target rotator. The azimuth value is determined by noting the value of the scale opposite the index mark as the rotator and scale revolve. The index is the line-of-sight from the radar antennas to the center of the rotator. (Azimuth angle data are transmitted to the data recorders by means of synchro signals.) The standard direction of rotation will be clockwise.

FIGURE B-5 TARGET ORIENTATION - AZIMUTH

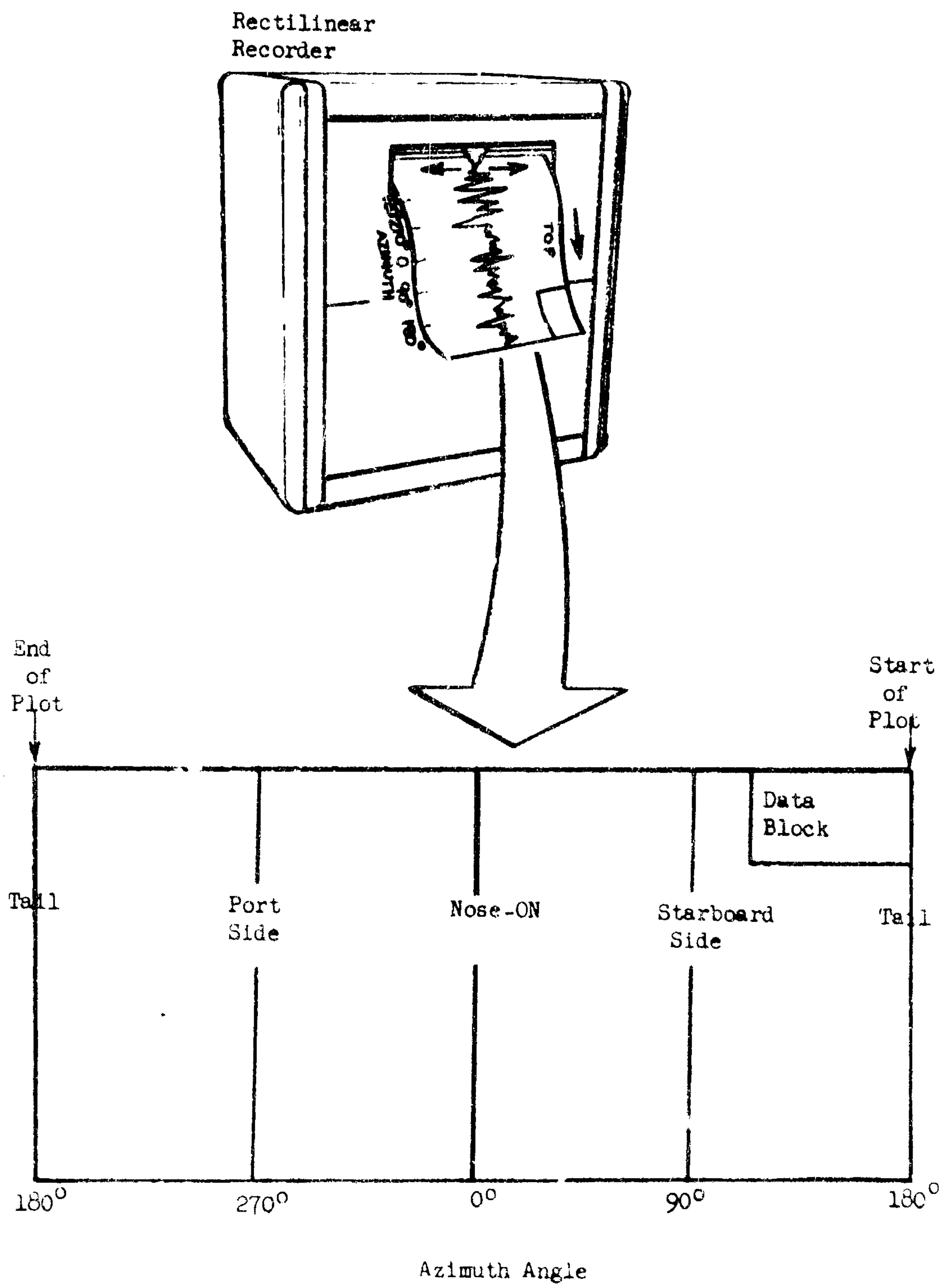


FIGURE B-6 FORMAT FOR RECTILINEAR PLOTS

.2, .4, 1.1, 2.0, or 4.0 degrees). Each of these recordings are preceded by the corresponding value of the rotator azimuth position. Since all three recorders are synchronized to azimuth positions of the rotator, the digital printouts, like the rectilinear plots, begin at the tail end of the vehicle and progress as if the vehicle were turning clockwise.

Header Format. Each digital data-run has a section of the punched paper tape, called the header, preceding it that contains information identifying the run. A format along with a standard set of symbols has been chosen which facilitates identification of different portions of the header. It also puts the paper tape in a form that could be used as an input to a digital computer. Symbols used in punched paper tape:

Carriage Return	
Line Feed	
Figures	
Letters	
Start Identification Information	(
Stop Identification Information	)
Start Data (exclamation point)	!
Plus Sign (quotation mark)	"
Minus Sign (dash)	-
Secondary Standard (ampersand)	&
Primary Standard (dollar sign)	$
Target (question mark)	?

The following format, consisting basically of three sections provides a uniform procedure for recording and identifying data:

a) Identification Information: This includes pertinent information applying to a particular run. This section, enclosed in parenthesis, includes control number, run number, date, time polarization, frequency, and brief description.

b) Transfer Standard Data: Data representing secondary signal levels follow the identification information. These data are preceded on the recording tape by an identifying symbol, ampersand (&), followed by a plus or minus sign, three digits, and an exclamation point, such as &" 40.0!. In this example "40.0 is a conversion constant. Conversion constants are discussed in the section below entitled Calibrating Digital Tape.

c) Target Data: Target data format is identical to transfer standard data format, with the exception that the ampersand is replaced by a dollar sign($) or a question mark (?), depending on the object being measured. The former is used for primary standards; the latter for vehicle, background, etc.

Calibrating Digital Tapes. Unlike the graphical forms of data, the digital printouts are not calibrated, and as such do not represent the actual radar cross sections. Information from the printouts can be calibrated, however, by subtracting the conversion constant from one-tenth the value of each digital printout. The conversion constant follows the symbol identifying the type of data. It is important to note that, as the recording tape progresses, each conversion constant supersedes all prior conversion constants. This calibration method is illustrated by the following example. Suppose one-tenth the value of the target signal level printout corresponding to 180 degrees is +58.0, and the conversion constant is "50.0 (decoded this equals 50.0 dbsm). Then the actual radar cross section of the target at 180 degrees would be +8 dbsm.

Calibration of Magnetic Tape will be as specified by each individual user.

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1. ORIGINATING ACTIVITY (Corporate author) Air Force Missile Development Center Holloman AFB, New Mexico 88330 Attention: MDRT	2a. REPORT SECURITY CLASSIFICATION Confidential 2b. GROUP 4
3. REPORT TITLE RADAR CROSS SECTION MEASUREMENTS OF 017-2, ROCKET EXHAUST PLUMES	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report	
5. AUTHOR(S) (Last name, first name, initial) Marlow, Harold C. Major, USAF	

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11. SUPPLEMENTARY NOTES AF contract with General Dynamics Fort Worth Division F29600-67-C0003	12. SPONSORING MILITARY ACTIVITY Rocket Test Facility at Edwards AFB, RPMCP (RTD)

13. ABSTRACT

Static radar cross section data of plumes from small liquid and solid propellant rocket motors were obtained at RAT SCAT, Air Force Missile Development Center, Holloman Air Force Base, New Mexico. A total of 42 monostatic measurements were made at UHF and upper L-band frequencies.

DD FORM 1 JAN 64 1473

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Security Classification

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radar Reflection						
Radar Cross Section						
Static Cross section						
Backscatter						
Reflectivity						
Radar						
Radar Echo						
Radar Targets						
Rocket Exhaust Plumes						
Ionization						
Flame Temperature						
Seeding						

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